The meetings were held on the campus of the University of Minnesota. The mathematicians were comfortably housed in Sanford Hall and had their dining room and social rooms there. Such provisions, which have become increasingly frequent in recent years, promoted very noticeably the pleasant character of the meetings because of the more personal contacts which are otherwise not so largely possible. The committee on arrangements under the chairmanship of Professor Brink planned carefully in advance for the convenience of the visitors, and as a result the matters of registration and of service throughout the week were carried out very smoothly.

About one hundred and twenty-five were present at the joint meeting on Friday evening, the majority remaining over the week-end and being reinforced by many new comers on Sunday and Monday. Coming just before the close of the Summer Session of the Society for the Promotion of Engineering Education, the Friday evening meeting formed an important link between that session and the meetings of the two mathematical organizations. Numerous parties drove about the beautiful boulevards of Minneapolis and vicinity on Saturday and Sunday.

A reception was held on Monday evening, Dean Ford of the Graduate School and Mrs. Ford welcoming the visiting mathematicians. A delightful luncheon was given for the visiting ladies on Tuesday noon at the Lafayette Club on Lake Minnetonka, automobiles being provided for all the ladies who attended.

The joint dinner was held on Wednesday evening at the Minneapolis Automobile Club. A cordial welcome was given in a speech by President L. D. Coffman. Professor Hedrick gave information as to the nature of the summer meetings at Los Angeles in September, 1932 and the incidental delights which may be found in connection with the meetings. He offered a resolution which was adopted by rising vote, expressing to the University authorities, and to the committee on local arrangements, our appreciation of their provision of the excellent and comfortable facilities afforded during the meetings. Brief speeches were made by Miss Weiss, who graciously invited the mathematicians to the New Orleans meetings in December and spoke of the many attractions in and about New Orleans; by Professor MacLean, who spoke in a very fitting manner of the cordial relations between the Dominion of Canada and the United States and called for definite efforts to promote active relations between the two countries; and by Professor Weaver, who commented very wittily on humorous incidents of the week and on the proposed plan for publicity in matters mathematical.

The American Mathematical Society held its thirty-seventh summer meeting and fifteenth colloquium from Tuesday to Friday, the colloquium lectures being given by Professor Marston Morse of Harvard University on "The calculus of variations." On Wednesday morning Professor Edmund Landau of the University of Göttingen gave an address by invitation on "Schnirelmann's theorem," and on Thursday morning Professor C. C. MacDuffee of Ohio State University gave an address by invitation on "Ideals in linear algebras." Sessions

for the reading of papers were held on Tuesday and Wednesday afternoons and Friday morning.

The Mathematical Association held sessions on Friday evening, Monday afternoon and Tuesday morning, Professor H. P. Hammond presiding at the first session and Vice-president C. N. Moore at the other two. The Association is under obligations to the committee consisting of Professor Warren Weaver (chairman), W. E. Brooke, Jewell C. Hughes, and J. H. Taylor for the preparation of an excellent program. Abstracts of some of the papers are given, numbered in accordance with the numbers of the papers.

Joint Session of the Association with the Society for the Promotion of Engineering Education

(1) "Some great engineer-mathematicians" by Dean C. S. Slichter, University of Wisconsin.

(2) "Some frequently overlooked mathematical principles of descriptive geometry" by Professor W. H. Roever, Washington University.

1. Professor Slichter pointed out the broad character of the learning of the mathematician of old, in particular the double field of Archimedes in pure mathematics and engineering. After giving a summary of the work of Leonardo, Euler, the Bernoullis and many others in other fields than mathematics alone, he contrasted Lord Kelvin and Heaviside. Even as an undergraduate Kelvin, as William Thomson, discovered the method of electrical images. Within one year of graduation he was called to the chair of natural philosophy at Glasgow and held this position for more than fifty years, combining throughout his career remarkable achievements in pure mathematics and applications to the telegraph, the submarine telegraph, electrical measurement, and so on, winning fame and wealth by his attainments. Heaviside, who came from a family of engineers, held office with a telegraph company for several years during which he showed that quadruplex telegraphy was possible and contributed to scientific journals papers of much ability and originality. But because of increasing deafness he spent all his life after the age of twenty-four as a scientific hermit at Torquay. His mathematical studies were profound and difficult to understand. They were often cut through the requirements of the editors, so that his work has been difficult to follow and to appraise. His inventions in telephonic developments are worth millions to all the world; but he did not take out patents on these and was not conspicuous or wealthy as compared with Lord Kelvin. Happily he was suitably honored in his last years. It is a cause for scientific hopefulness in this day of over-specialization that men like these two do appear at culminating epochs in the affairs of men.

2. The purpose of Professor Roever's paper is to call attention to some of the mathematical principles of Descriptive Geometry which are either overlooked or understressed, due to the fact that the subject is now taught almost exclusively by teachers of drawing rather than by mathematicians.

After tracing the evolution of Descriptive Geometry from the art of stone-cutting, the problem of this subject was precisely stated as that of representing the objects of space by figures in a plane and of solving the problems of space by constructions which can be executed in the plane. It was then pointed out that the sight-process leads to the methods of projection as a means of representation and that this method while sufficient for the artist has to be augmented in order to provide a means for obtaining an unambiguous correspondence between space and the plane so that the problems of space may be solved by constructions in the plane. Thus one is led to methods of double projection such, for instance, as the Mongean and axonometric methods as well as to methods of double trace, such as the method of free perspective and the clinographical method (including the topographical method). It was also shown that certain methods of double projection would have no significance without such fundamental theorems of Descriptive Geometry as the theorem of Schwarz (or the theorem of Gauss) for orthographic projection, and the theorem of Pohlke for oblique projection. Several of the problems of space were solved by each of the methods above mentioned. Attention was also called to methods of constructing the bounding curves of projections of surfaces.

FIRST SESSION OF THE ASSOCIATION

(3) "The present situation in projective differential geometry" by Professor E. P. LANE, University of Chicago.

(4) "Business and statistics" by Professor H. C. CARVER, University of Michigan.

3. Professor Lane first called attention to the past, or history, of Projective Differential Geometry. Then he described the present situation as reflected by the literature. Finally, he pointed out some of the directions which the development of this science might follow in the future.

The history of projective differential geometry is comprised in two distinct periods; first, that of the discovery of isolated results now recognized to be of a projective differential nature; second, that of the conscious study of projective differential geometry and of the organization of theories of this subject. The earlier period extended over approximately the two and one-quarter centuries ending in 1875. During this time results later incorporated in the science of projective differential geometry were announced by such men as Dupin, Chasles, P. Serret, Moutard, Hermite, Lie, and Darboux. Since 1875 projective differential geometry has been consciously studied first by Halphen and later by Wilczynski, Fubini, and others.

The present situation in projective differential geometry may be considered as reflected by the literature, and more particularly, by the books which have been published or have been announced on this subject. Of the books actually published there are five (one in two volumes) by Wilczynski, Tzitzéica, Fubini, and Cech. There are two books announced but not yet published, one by Bompiani and one by Lane.

Any predictions as to the course of future development of a science are necessarily somewhat uncertain but may be interesting nevertheless. One unsolved problem is to construct a projective differential theory of a curved variety of k dimensions immersed in a linear space of n dimensions, with $1<k<n-1$ and $n>4$, analogous to Wilczynski's or Fubini's theory of a surface in ordinary space. Sets of varieties which are the loci of linear spaces in correspondence are being studied by means of certain systems of linear differential equations of the first order. Another topic proposed for study is projective differential geometry *in the large*. And it seems quite likely that sufficient attention has not yet been given to the projective differential study of singularities of configurations.

4. Professor Carver called attention to the fact that the trend of business statistics is, and necessarily must be, toward the mathematical end of the statistics spectrum, and stressed the fact that mathematical statistics—essentially a combination of probability and pure mathematics—is sadly in need of a rigor which only specialists in pure mathematics can supply. After defining briefly several statistical concepts such as *average, standard deviation, frequency distribution*, etc., and describing briefly the theory of sampling, he went on to describe the theory of inverse sampling, referring to the work recently accomplished by R. A. Fisher and to the excellent survey by Professor P. R. Rider in the *Annals of Mathematics* for October, 1930. He concluded with a discussion of business statistics, expressing regret that that phase of business statistics which deals with the analysis and projection of time series rests inexcusably on an exceedingly unstable foundation. This work is being done by economists and "professional forecasters" who are far more interested in making predictions than they are in estimating the probability that the actual occurrences will differ from their forecasts by more than a specified per cent. Professor Carver insisted that with very few exceptions estimates of the future terms in time series should be expressed numerically and in precisely the same terms that will subsequently be employed in recording the corresponding facts for historical purposes. When this is done, we can at least obtain empirical approximations for the probable errors of these estimates and we may then expect that competition among forecasters will result both in an increase in the reliability and in a corresponding decrease in the number of forecasters. It is highly desirable that our students of business administration possess a sufficient mathematical background to enable them to know at what point in their work they should ask the aid of mathematically trained statisticians. Mathematical statisticians are not at the present time capable of solving all the problems that might reasonably be submitted to them. For instance, the entire theory of sampling will probably require fundamental alterations in order that it may be applied properly to time series, since each sample contains ordered variates with respect to time. Professor Carver's plea was that mathematicians should realize the importance of this branch of applied mathematics, since the business world will soon be insisting on a better cooperation of mathematics and economics.

SECOND SESSION OF THE ASSOCIATION

(5) "Some mathematical aspects of the new physics" by Professor J. H. VAN VLECK, University of Wisconsin, by invitation.

(6) "Functions of the Mathematical Association of America," a retiring presidential address by Professor J. W. YOUNG, Dartmouth College.

5. This paper will appear in this MONTHLY early in 1932.

6. This paper will appear in this MONTHLY early in 1932.

MEETING OF THE BOARD OF TRUSTEES

Eight trustees were present at the meeting on Monday evening.

The following thirty-five persons and one institution were elected to membership on applications duly certified:

To Individual Membership

H. M. ACKLEY, A.M. (Olivet). Prof., Western State Teachers Coll., Kalamazoo, Mich.

SISTER ALICE IRENE, A.M. (St. Canisius). Prof., Coll. of St. Rose, Albany, N. Y.

N. B. ALLISON, A.M. (Kentucky). Instr., Univ. of Kentucky, Lexington, Ky.

MAX ASTRACHAN, A.M. (Brown). Instr., Brown University, Providence, R. I.

N. A. BANKS, M.S. (Wilberforce). Prof., Tillotson Coll., Austin, Tex.

J. I. BOHNERT, Jr. Senior, Carnegie Inst. of Tech., Pittsburgh, Pa.

G. M. BROWN, M.Sc. (Univ. of Leeds, England) Tiffin, Ohio

C. E. BUELL, A.B. (Oberlin), Grad. Student, Ohio State Univ., Columbus, Ohio

W. H. H. COWLES, A.M. (Columbia). Prof., Head of Dept., Math and English, Pratt Inst., Brooklyn, N. Y.

J. H. EDMONSTON, A.B. (George Washington). 1441 Fairmont St. N. W., Washington, D.C.

J. D. ELDER, Ph.D. (Calif. Inst. of Tech.). Instr., Univ. of Michigan, Ann Arbor, Mich.

DONALD FAULKNER, A.B. (Stetson). Prof., J. B. Stetson Univ., DeLand, Fla.

VIRGINIA I. FELDER, M.S. (Tulane). Head of Dept., Copiah-Lincoln Junior Coll., Wesson Miss.

GEORGE FISANICK, A.B. (Pennsylvania State). Grad. student, Univ. of Michigan, Ann Arbor, Mich.

J. M. GLEASON, A.M. (California). Instr., State Teachers Coll., San Diego, Calif.

H. R. GRUMMANN, A.M. (Minnesota). Asst. Prof., Washington Univ., St. Louis, Mo.

M. L. HARTUNG, Ph.D. (Wisconsin). Instr., Teaching of Math., Wisconsin High School, Madison, Wis.

A. E. HEINS, Student, Massachusetts Inst. of Tech., Cambridge, Mass.

A. S. HOUSEHOLDER, A.M. (Cornell). Asst. Prof., Washburn Coll., Topeka, Kans.

D. V. LANHAM. Student, New River State Coll., Montgomery, W. Va.

W. S. LITTERICK, M.S. (Brown). Instr., Peddie School, Hightstown, N. J.

N. B. MACLEAN, Ph.D. (Chicago). Prof., Appl. Math., Joint Chmn, Dept. of Math., McGill Univ., Montreal, Canada

A. W. MARTIN, Ph.D. (Chicago). Prof., Coll. of Puget Sound, Tacoma, Wash.

MARY E. MEADE, A.M. (Virginia). Acting Dean of Women, Martin Coll., Pulaski, Tenn.

H. J. MILES, Ph. D. (California). Instr., Univ. of Illinois, Urbana, Ill.

S. S. MORRIS, M.S. (West Virginia). Prof., Broaddus Coll., Philippi, W. Va.

BROTHER NORBERT, M.S. (Notre Dame). Instr., St. Edwards Univ., Austin, Tex.

EUNICE C. ORR, A.M. (Indiana). Teacher, High School, Arcadia, Ind.

A. L. O'TOOLE, Ph.D. (Michigan). National Research Fellow, Univ. of Minnesota, Minneapolis, Minn.

W. D. PECK, A.B. (Lebanon Valley). Head of Dept., Asheville School for Boys, Asheville, N. C.

FRED ROBERTSON, A.M. (Indiana). Instr., Iowa State Coll., Ames, Iowa

MABEL F. SCHMEISER, Ph.D. (Ohio State). Head of Dept., State Teachers Coll., Wayne, Nebr.

S. J. SMITH, A.M. (Pittsburgh). Instr. State Teachers Coll., Lock Haven, Pa.

RUSSELL SULLIVAN, A.B. (Yale). 1431 N. Meridian St., Indianapolis, Ind.

F. G. WEIMER, M.S. (West Virginia). Grad. Asst., West Virginia Univ., Morgantown, W. Va.

To Institutional Membership

PENNSYLVANIA COLLEGE FOR WOMEN, Pittsburgh, Pa.

The Trustees voted to approve the dates of August 29–September 2, 1932, for the mathematical meetings at Los Angeles. They also authorized the president to appoint a committee on publicity in mathematics with himself as chairman, and they adopted a resolution expressing their appreciation of the action of the officers of the Society for the Promotion of Engineering Education in organizing and administering a summer school for teachers of mathematics to engineering students, recognizing also the very efficient work of Professor H. P. Hammond, director of the summer sessions, and of Dean O. M. Leland, the chairman of the session at Minneapolis and, as well, the part of the University of Minnesota in the contribution of its equipment and its moral and financial support.

W. D. CAIRNS, *Secretary*

THE S.P.E.E. SUMMER SESSION FOR TEACHERS OF MATHEMATICS TO ENGINEERING STUDENTS

By H. P. HAMMOND, Polytechnic Institute of Brooklyn

In cooperation with the Mathematical Association of America and the American Mathematical Society, the Society for the Promotion of Engineering Education held at Minneapolis a session of its Summer School for Engineering Teachers, devoted to the study and discussion of methods of teaching undergraduate courses in mathematics to engineering students. The session was held just prior to the annual meetings of the mathematical societies, beginning on August 24 and concluding September 5.

These Summer School sessions, which were begun in 1927, are held each year in various institutions throughout the country and are devoted in turn to different divisions of the engineering curriculum. The session of this summer was the first in the field of mathematics. Its success is evidenced by the fact that the attendance was the largest of any session which the S.P.E.E. has held. Eighty-nine teachers, representing the various teaching ranks in almost equal proportion, were present during the session. This group represented sixty different institutions in thirty-three states and provinces of Canada. Such widely separated localities as Massachusetts and Vermont at one extreme, and California at the

other, were included. In comparison with groups at other sessions, the mathematics conference was marked, to an unusual degree, by the maturity and responsible positions held by those who attended. For the first time, a number of women members of engineering and other faculties were in attendance.

The various periods of the session were conducted chiefly as lectures presented by members of the staff, followed by open discussions from the floor. The program was arranged in five principal divisions:

1. A series of lectures on educational principles—learning and teaching—by Professor Francis T. Spaulding, of the Graduate School of Education at Harvard University.

2. The content and method of presenting undergraduate courses in mathematics for engineering students. This was the principal division of the program and consisted of a series of lectures beginning with trigonometry and extending through differential equations. Professors E. R. Hedrick, Louis O'Shaughnessy, W. E. Brooke, W. J. Berry, E. V. Huntington and Warren Weaver were the staff members who conducted this portion of the program.

3. Advanced mathematics—a few lectures devoted to various phases of mathematics extending beyond the customary undergraduate subjects, by Professors Dunham Jackson, H. L. Rietz, Warren Weaver, C. N. Moore and Leigh Page.

4. Certain applications of mathematics in the field of engineering practices, by Professor Stephen Timoshenko and Dr. T. C. Fry.

5. History and miscellaneous. Two lectures were delivered by Professor R. C. Archibald on the history of mathematics, and a number of other miscellaneous topics were discussed by Dean O. M. Leland, Dean M. E. Haggerty and Dean C. S. Slichter.

Throughout the two weeks of the session the entire group was housed at Sanford Hall, a dormitory of the University of Minnesota, and the meetings were conducted in buildings of the College of Engineering and Architecture of the University.

In addition to the cooperation of the two mathematical societies, the session was sponsored by the Engineering Foundation and was held in cooperation with the University of Minnesota. Dean O. M. Leland, of the University of Minnesota, served as the Local Director, and Professor C. A. Herrick as the Secretary.

The S.P.E.E. will publish, during the coming year, a series of bulletins or monographs giving the substance of many of the lectures presented. These will appear in the Journal of Engineering Education and as separately bound booklets, which will be available for circulation and can be obtained by applying to the Director of Summer Schools, Society for the Promotion of Engineering Education, 99 Livingston Street, Brooklyn, N. Y.

THEOREMS RELATING TO THE PRE-GRECIAN MATHEMATICS

By G. A. MILLER, University of Illinois

In a previous number of this Monthly[1] the present writer directed attention to a few theorems relating to the *Rhind Mathematical Papyrus*. The present article is devoted to the noting of several other theorems relating to the pre-Grecian mathematical developments. The fact that theorems which were not even formulated at the time may nevertheless have exerted a powerful influence on the development of our subject is forcibly illustrated by the history of elementary geometry. It is well known that the properties which form the subject matter of our modern elementary geometry are the invariants under a group of transformations which was called the principal group by F. Klein. On the other hand, the ancients developed many of the theorems of this elementary geometry without formulating the concept of group of transformations and without knowing that they were studying invariants under such a group.

According to H. Poincaré the concept of group was one of the earliest mathematical concepts to be acquired by the human race. If this is correct it would seem that our general histories of mathematics should exhibit evidences of this concept in some of the earliest mathematical developments. Probably one reason why this has not been done up to the present time is that it requires a keen mathematical insight to comprehend some of these evidences, especially since there is not a single instance on record where the ancient people formulated explicitly a group theory theorem. It is however true that if we study some of the early mathematical developments in the light of such theorems we can now discover clarifying and guiding principles which otherwise would not present themselves and hence a knowledge of these theorems is useful to the modern mathematical historian.

One of the most important and most elementary groups of all mathematics is the one formed by the totality of the positive rational numbers when they are combined by multiplication. While it should not be assumed that the pre-Grecian mathematicians formulated the theorem that these numbers constitute an *abelian* group when they are thus combined it is interesting to note evidences of their recognition of its commutative property. Even in the *Rhind Mathematical Papyrus* the multiplier and multiplicand are sometimes interchanged, and in the seventh book of Euclid's *Elements* it is noted explicitly that the product of two positive real numbers is independent of their order, but it was not until the early part of the nineteenth century that a special term *commutative* was introduced for this fundamental property by F. Servois in volume 5 (1814) of *Annales de Mathématiques*, page 98. It is very interesting to note in the development of mathematics evidences of such distantly related steps towards the proper recognition of such fundamental concepts.

In the introduction to the second edition (1927) of his *Theorie der Gruppen*

[1] Vol. 38 (1931), p. 194.

von endlicher Ordnung A. Speiser speaks of a prehistoric group theory extending back at least as far as 1500 B.C., and of a revival thereof in about 1600 A.D. which failed to command much interest soon thereafter. These conclusions were based largely on the symmetry involved in ancient ornaments and on the study of regular figures in ancient times. These figures naturally suggest the movements of space which transform them as entireties into themselves but interchange their parts. In particular, the eight movements of space which transform into itself a square constitute an interesting non-abelian group now known as the octic group. Since this group is related to a unit of surface measurement employed in very ancient times one might be inclined to think that its properties were known to some of the pre-Grecian mathematicians, but there is no historical evidence which proves that even the ancient Greeks had become familiar with these properties notwithstanding their very elementary character.

Among the symmetrical geometric figures the circle and the sphere are outstanding and it has recently been stated that the ancient Egyptians used the theorem that the area of a hemisphere is equal to that of two great circles on the corresponding sphere.[2] It is however not quite accurate to say that they found the exact area of a hemisphere since their rule for finding the area of a circle was quite inaccurate from the modern point of view. While the circle naturally appealed to the ancient peoples on account of its symmetry and the fact that it admits a group of rotations of infinite order yet we have no evidence that a single pre-Grecian mathematician developed a method by means of which the value of the ratio of its circumference to its diameter can be found to any desired degree of accuracy. Such negative facts in the history of pre-Grecian mathematics are as important as the positive ones for the purpose of securing a correct understanding of this history.

Similarly we should emphasize negative facts relating to the influence of the concept of group on early mathematical developments in order to secure a correct notion of this influence. One such negative fact is furnished by the late general adoption of a number system which forms a group with respect to the operation of addition. The most fundamental such system is furnished by the positive and negative integers, including zero. It is well known that the use of negative numbers was not fully established until about the beginning of the nineteenth century and that such noted mathematicians as H. Cardan and R. Descartes expressed very erroneous views relating thereto. Moreover, according to the *Rhind Mathematical Papyrus* by A. B. Chace, volume 1, page 6, "the Egyptians could not solve directly the problem of finding the multiplicand when the multiplier and product were given." This seems to imply that the group concept did not fully dominate their operation of multiplication.

Our modern mathematics involves many arbitrary divisions which do not circumscribe the developments relating to our subject. That is, these develop-

[2] W. W. Struve, *Quellen und Studien zur Geschichte der Mathematik*,—Quellen, vol. 1 (1930), p. 172.

ments penetrate these lines of division and exhibit mathematics as a unit. In particular, we now frequently speak of the four fundamental rational operations and the student is sometimes led to think that these operations are distinct instead of interpenetrating. It is somewhat misleading to say that the operations of addition, subtraction, multiplication, and division appear explicitly in the *Rhind Mathematical Papyrus*. According to J. Tropfke's *Geschichte der Elementar-Mathematik*, volume 1 (1930), page 73, the ancient Egyptians were not conscious of actual calculating operations. Even the ancient Greeks used many different words for the same fundamental rational operation and thus exhibit that in their times there was still lacking a well established custom as regards the use of these operations and the value of a drill therein so as to replace the need of penetrating insight by a formal method.

With respect to the group concept our four fundamental rational operators reduce to two, viz., addition and multiplication, since the inverse operations belong to the group which involves the direct ones. The fact that we persist in speaking of four fundamental operations notwithstanding this obvious theorem seems to imply that the group concept fails to dominate here. On page 70 of the volume on the history of mathematics noted in the preceding paragraph J. Tropfke remarks that one might assert that the number of the different operations formerly used was inversely proportional to the mathematical advancement. This evidently does not apply to the pre-Grecian mathematics and it may be too early to observe any tendency to reduce our four fundamental operations to two on account of an increasing familiarity with the group concept. At any rate it is interesting to note the connection between the group concept and these operations and the possibility of such a reduction.

A rational number may be defined as the infinite set of numbers which are equivalent to a fixed common fraction.[3] An operation like $a+b=c$ may therefore be regarded as a certain combination of the infinite sets represented by the fixed numbers a and b respectively into a single set represented by c. The fact that there is an infinite set of common fractions which are separately equal to the common fraction 2/1, for instance, and that when we perform the ordinary rational operations with respect to fixed numbers we may also regard them as operations with infinite sets of equivalent numbers was probably not explicitly noted by any pre-Grecian mathematicians but they certainly did recognize the equivalence of various common fractions and hence may have been vaguely inspired by this broader view of the fundamental operations of arithmetic. The statement that 2 times 3 is 6 becomes much more significant if we think of the infinitudes of equivalent numbers involved therein.

The ancient Sumerians and the ancient Babylonians seem to have been the only pre-Grecian peoples who made even a partial use of a positional numerical notation. It should be noted that while every positive rational integer can be represented positionally by means of k distinct integer symbols with respect to

[3] Cf. E. Landau, Grundlagen der Analysis, 1930, p. 35.

the arbitrary natural number $k>1$ as a base it is not possible to select this base so that every positive common fraction can be represented positionally in a finite form by means of a starting symbol and these k integer symbols. In fact, this can obviously be done only when the denominator of the common fraction involves only prime factors which divide k. This marked difference as regards the possible positional notation of positive integers and of positive common fractions is fundamental in the history of elementary mathematics from a higher standpoint and hence should be emphasized therein.

By using 60 for k the ancient Babylonians were able to represent the common fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, and $\frac{1}{6}$ by the integers 30, 20, 15, 12, and 10 respectively. Just as the *Rhind Mathematical Papyrus* seems to exhibit the predominating interest of the ancient Egyptians in the use of common fractions so the large base 60 may exhibit the predominating interest of the ancient Babylonians in the use of these fractions. Recently Professor O. Neugebauer stated that the extensive so-called multiplication tables of the ancient Babylonians had for their object the conversion of common fractions into sexagesimal ones, *Quellen und Studien zur Geschichte der Mathematik*,—Studien, volume 1 (1930), page 193. This seems to support the view just noted, and these tables must have furnished many illustrations of the difficulties involved in representing common fractions positionally.

An invariant under similarity transformations which was recognized very early is the constant ratio between the circumference and the diameter of a circle as the size of the circle is varied. The fact that the circumferences of all of these circles are now commonly supposed to make the same angle with their diameters but when all of them are tangent to a given line at the same point thereof they may be so arranged and ordered that any one of these angles lies within all of those which precede it exhibits the need of postulates in elementary geometry and may help to explain why this need seems to have been first recognized in connection with this subject. Notwithstanding this obvious need of postulates there is no evidence tending to prove that any pre-Grecian mathematicians made explicit use of postulates. They did however verify many of their results and in some cases these verifications constitute proofs. The most general theorems used by the pre-Grecian mathematicians were however not proved by them in any extant work and this represents the widest difference between the pre-Grecian mathematics and that of the ancient Greeks.

It has recently been discovered that the fundamental theorem commonly known as the Pythagorean theorem was probably used by the ancient Babylonians but no evidence of a proof by them has yet been found. Since this theorem relates to an infinite number of triangles it cannot be proved by verifications alone while the theorem that four things can be permuted in 24 distinct ways can obviously be proved in this way. The table of unit fractions with which the *Rhind Mathematical Papyrus* opens also furnishes special theorems which can be thus proved. The fact that the ancient Egyptians gave so many verifications exhibits a tendency on their part towards proving mathematical results instead

of merely accepting them. An unduly unfavorable impression in regard to ancient Egyptian mathematics has been made during recent years by various writers who asserted that the area of a triangle was found therein by multiplying one-half the base by a side instead of by the altitude. Recently W. W. Struve seems to have proved conclusively that the ancient Egyptians used a correct theorem in this connection; *Quellen und Studien zur Geschichte der Mathematik*,—Quellen, volume 1 (1930), page 172.

ON THE DERIVATIVES OF $(w/\sin w)^k$ AT $w=0$

By CARROLL V. NEWSOM, University of New Mexico

Recently the writer had occasion to investigate the higher derivatives of the function, $f(w)=(w/\sin w)^k$. This investigation led to the formulation of the following theorem which appears to be new and noteworthy:

THEOREM:

$$(1)\qquad \left[\frac{d^r}{dw^r}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}=\frac{\sum\alpha_1\alpha_2\cdots\alpha_r}{{}_{k-1}C_r}.$$

in which k is any given positive integer[1] $\geqq 2$, $1\leqq r\leqq k-1$; *and where* $\sum\alpha_1\alpha_2\cdots\alpha_r$ *denotes the sum of the* $\binom{k-1}{r}$ *products of r factors each formed by taking the possible combinations of the* $(k-1)$ *quantities*; $\pm(k-2)i$, $\pm(k-4)i$, $\cdots$, $\left\{\begin{smallmatrix}\pm i\\0\end{smallmatrix}\right\}$ *r at a time*; *i having the usual interpretation,* $i=\sqrt{(-1)}$, *and where* $\left\{\begin{smallmatrix}\pm i\\0\end{smallmatrix}\right\}$ *is understood as* $\pm i$ *or* 0 *according as k is odd or even.*[2]

Proof: To establish this theorem it is sufficient, after defining the right member of (1) to be unity in case $r=0$, to verify the following identity in x where x is regarded as an auxiliary variable:

$$(2)\qquad \sum_{r=0}^{k-1}\left\{\frac{(k-1)!}{r!(k-r-1)!}\left[\frac{d^r}{dw^r}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}x^{k-r-1}\right\}$$
$$\equiv\sum_{r=0}^{k-1}\left[\sum\alpha_1\alpha_2\cdots\alpha_r\right]x^{k-r-1}.$$

This is equivalent to (1) because the coefficients of like powers of x on the right and on the left sides of (2) will necessarily be equal if (2) is an identity, and the equating of these coefficients gives precisely (1) wherein r ranges over the prescribed range; namely, $1\leqq r\leqq k-1$.

Inasmuch as (2) is readily found by trial to be true in case k is small, as $k=2$ and $k=3$, the inductive process of proof will be employed.

Assuming then the correctness of (2) for any particular k, we proceed to show that it holds true also when k is replaced by $k+2$. To do this let us first

[1] Evidently a further definition of the symbols employed is necessary when $k=1$.

[2] Contrast the result here given with the result obtained, for example, by Schwatt, *Introduction to Operations with Series*, University of Pennsylvania Press, (1924), page 74.

multiply both members of (2) by $(x+ki)(x-ki)$; that is, by x^2+k^2. The product of the left member by k^2 is evidently

$$(3)\qquad \sum_{r=0}^{k-1}\left\{\frac{k^2(k-1)!}{r!(k-r-1)!}\left[\frac{d^r}{dw^r}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}\right\}x^{k-r-1}.$$

Before multiplying the same member of (2) also by x^2 it is desirable to write it in the form

$$(4)\qquad \begin{aligned} &x^{k-1}+\frac{(k-1)!}{(k-2)!}\left[\frac{d}{dw}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}x^{k-2}\\ &\quad+\sum_{r=0}^{k-1}\left\{\frac{(k-1)!(k-r-2)(k-r-1)}{(r+2)!(k-r-1)!}\left[\frac{d^{r+2}}{dw^{r+2}}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}x^{k-r-3}\right\}. \end{aligned}$$

Since $[d/dw(w/\sin w)^k]_{w=0}=0$, the product of (4) and x^2 becomes

$$(5)\quad x^{k+1}+\sum_{r=0}^{k-1}\left\{\frac{(k-1)!(k-r-2)(k-r-1)}{(r+2)!(k-r-1)!}\left[\frac{d^{r+2}}{dw^{r+2}}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}x^{k-r-1}\right\}.$$

In considering the product of the right member of (2) and x^2+k^2, it is necessary to recall the interpretation of $\sum\alpha_1\alpha_2\cdots\alpha_r$ as originally given in the statement of the theorem. If we employ the root-coefficient relations of the elementary theory of equations the right member of (2) is seen to be

$$[x+(k-2)i][x-(k-2)i][x+(k-4)i][x-(k-4)i]\cdots\left\{\begin{matrix}[x+i][x-i]\\ x\end{matrix}\right\}.$$

Hence it becomes evident that the product of this right member by x^2+k^2 is

$$(6)\quad [x+ki][x-ki][x+(k-2)i][x-(k-2)i][x+(x-4)i][x-(k-4)i]\cdots\left\{\begin{matrix}[x+i][x-i]\\ x\end{matrix}\right\}.$$

This product may be expressed in the form

$$(7)\qquad x^{k+1}+\sum_{r=0}^{k-1}[\,\textstyle\sum\alpha_1\alpha_2\cdots\alpha_{r+2}]x^{k-r-1},$$

where the groups of factors employed in $\sum\alpha_1\alpha_2\cdots\alpha_{r+2}$ are now all the possible combinations of the quantities $\pm ki$, $\pm(k-2)i$, $\cdots$, $\left\{\begin{matrix}\pm i\\ 0\end{matrix}\right\}$ taken $r+2$ at a time. Hence, having assumed the truth of (2) for any given value of k, we have the following identity in x:

$$(8)\qquad \begin{aligned} &x^{k+1}+\sum_{r=0}^{k-1}\left\{\frac{k^2(k-1)!}{r!(k-r-1)!}\left[\frac{d^r}{dw^r}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}\right.\\ &\quad\left.+\frac{(k-1)!(k-r-2)(k-r-1)}{(r+2)!(k-r-1)!}\left[\frac{d^{r+2}}{dw^{r+2}}\left(\frac{w}{\sin w}\right)^k\right]_{w=0}\right\}x^{k-r-1} \end{aligned}$$

$$\equiv x^{k+1} + \sum_{r=0}^{k-1} [\sum \alpha_1 \alpha_2 \cdots \alpha_{r+2}] x^{k-r-1}.$$

But we may now show that the left member of (8) is identically equal to

$$(9) \qquad x^{k+1} + \sum_{r=0}^{k-1} \left\{ \frac{(k+1)!}{(r+2)!(k-r-1)!} \left[\frac{d^{r+2}}{dw^{r+2}} \left(\frac{w}{\sin w} \right)^{k+2} \right]_{w=0} x^{k-r-1} \right\},$$

which statement is equivalent to showing that (2) holds true, as desired, when k is replaced by $k+2$ inasmuch as (8) then will assume the form

$$\sum_{r=0}^{k+1} \left\{ \frac{(k+1)!}{r!(k-r+1)!} \left[\frac{d^r}{dw^r} \left(\frac{w}{\sin w} \right)^{k+2} \right]_{w=0} x^{k-r+1} \right\}$$

$$\equiv \sum_{r=0}^{k+1} [\sum \alpha_1 \alpha_2 \cdots \alpha_r] x^{k-r+1}$$

which is what results from (2) when k is replaced by $k+2$. To do this, it suffices to show that the corresponding coefficients of the like powers of x in (9) and in the left member of (8) are equal. In other words, it is sufficient to show that

$$\frac{k^2(k-1)!}{r!(k-r-1)!} \left[\frac{d^r}{dw^r} \left(\frac{w}{\sin w} \right)^k \right]_{w=0}$$

$$(10) \qquad + \frac{(k-1)!(k-r-2)(k-r-1)}{(r+2)!(k-r-1)!} \left[\frac{d^{r+2}}{dw^{r+2}} \left(\frac{w}{\sin w} \right)^k \right]_{w=0}$$

$$= \frac{(k+1)!}{(r+2)!(k-r-1)!} \left[\frac{d^{r+2}}{dw^{r+2}} \left(\frac{w}{\sin w} \right)^{k+2} \right\}_{w=0}.$$

Now, let us assume for the moment the correctness of (10). If we multiply both its members by

$$\frac{(r+2)!(k-r-1)!}{(k-1)!},$$

we obtain the equivalent relation

$$(11) \quad (k-r-2)(k-r-1) \left[\frac{d^{r+2}}{dw^{r+2}} \left(\frac{w}{\sin w} \right)^k \right]_{w=0}$$

$$+ k^2(r+1)(r+2) \left[\frac{d^r}{dw^r} \left(\frac{w}{\sin w} \right)^k \right]_{w=0}$$

$$- k(k+1) \left[\frac{d^{r+2}}{dw^{r+2}} \left(\frac{w}{\sin w} \right)^{k+2} \right]_{w=0} = 0.$$

For convenience, let us now write k in the form $k=-p$, $p\leqq -2$. Then we may rewrite (11) in the form

$$(12)\quad (p+r+2)(p+r+1)\left[\frac{d^{r+2}}{dw^{r+2}}\left(\frac{\sin w}{w}\right)^p\right]_{w=0} + p^2(r+1)(r+2)\left[\frac{d^r}{dw^r}\left(\frac{\sin w}{w}\right)^p\right]_{w=0} - p(p-1)\left[\frac{d^{r+2}}{dw^{r+2}}\left(\frac{\sin w}{w}\right)^{p-2}\right]_{w=0} = 0.$$

If p now be treated temporarily as a variable, it is a matter of observation to see that the left member of (12) is a rational polynomial in p of degree $r+4$. Hence, if it can be shown that the algebraic equation (12) is satisfied by every positive integer p, its identical nature for all real values of p is established and hence the identical nature of (11) is established for all real values of k; in particular, for the given positive integral value with which we are concerned. In order to do this, it is desirable at this point to recall that

$$(13)\quad \left[\frac{d^r}{dw^r}\left(\frac{\sin w}{w}\right)^p\right]_{w=0} = \frac{r!}{(r+p)!}\left[\frac{d^{r+p}}{dw^{r+p}}\sin^p w\right]_{w=0};$$

where p is any positive integer. This follows immediately from a consideration of

$$\frac{d^{r+p}}{dw^{r+p}}\left[w^p\left(\frac{\sin w}{w}\right)^p\right]_{w=0}.$$

In fact, if we employ the theorem of Leibnitz upon the derivative of the product within the bracket, it is seen that the substitution of $w=0$ causes all derivatives of w^p to vanish except the pth. The term corresponding to this derivative is

$$\frac{(r+p)!}{r!}\left[\frac{d^r}{dw^r}\left(\frac{\sin w}{w}\right)^p\right]_{w=0}.$$

Relation (13) then follows immediately.

Employing (13) upon each term of (12) gives

$$(14)\quad \left[\frac{d^{r+p+2}}{d^{r+p+2}}\sin^p w\right]_{w=0} + p^2\left[\frac{d^{r+p}}{dw^{r+p}}\sin^p w\right]_{w=0} - p(p-1)\left[\frac{d^{r+p}}{dw^{r+p}}\sin^{p-2} w\right]_{w=0} = 0.$$

Now the first term of (14) may be written

$$\left[\frac{d^{r+p}}{dw^{r+p}}\left(\frac{d^2}{dw^2}\sin^p w\right)\right]_{w=0}, \tag{15}$$

which becomes, after actually obtaining the second derivative involved,

$$p(p-1)\left[\frac{d^{r+p}}{dw^{r+p}}\sin^{p-2}w\right]_{w=0} - p^2\left[\frac{d^{r+p}}{dw^{r+p}}\sin^p w\right]_{w=0}. \tag{16}$$

The substitution of this result in (14) causes it to vanish identically. It is now readily observed that it is possible to retrace our steps from this identity to establish the validity of (10).

In summarizing, we may say that we have thus established the equality of the corresponding coefficients of like powers of x in (9) and in the left member of (8). Thus (2) also holds true when k is replaced by $k+2$. Hence the induction is complete and the theorem is established.

ON THE REPRESENTATION OF A LORENTZ TRANSFORMATION BY MEANS OF TWO-ROWED MATRICES

By FRANCIS D. MURNAGHAN, Johns Hopkins University

The connection between quaternions and two rowed matrices is very well known[1] and an application of this connection to questions arising, in modern physical theory, from consideration of the spinning electron has been given in a very interesting recent paper by van der Waerden.[2] It is the purpose of the present note to treat in a very elementary way the ideas of van der Waerden and to give some results not mentioned in his paper.

If we have a two-rowed square matrix

$$\eta = \left\| \begin{matrix} \eta_1^{\,1} & \eta_2^{\,1} \\ \eta_1^{\,2} & \eta_2^{\,2} \end{matrix} \right\|$$

we may set $\eta_1^{\,1} = ct - x$; $\eta_2^{\,2} = ct + x$; $\eta_2^{\,1} = y + iz$; $\eta_1^{\,2} = y - iz$ and the determinant of the matrix then appears in the form $c^2t^2 - x^2 - y^2 - z^2$. If the four quantities (x, y, z, ct) are real the elements $\eta_1^{\,1}$, $\eta_2^{\,2}$ of the matrix η must be real whilst the elements $\eta_2^{\,1}$, $\eta_1^{\,2}$ must be conjugate imaginaries: $\eta_1^{\,2} = \bar{\eta}_2^{\,1}$ (in technical terms the matrix η must be *Hermitian*). Let us now transform the matrix η into another matrix ζ by means of two non-singular matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ as follows:

$$\zeta = \boldsymbol{A}\eta\boldsymbol{B} \tag{A}$$

and ask the conditions on the transforming matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ that when (x, y, z, ct) are real the quantities (x', y', z', ct') derived from ζ by means of the equations

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[1] Cf. L. E. Dickson, *Modern Algebraic Theories*, pp. 46, 110.

[2] B. L. van der Waerden, *Spinoranalyse*, Göttinger Nachrichten (1929), pp. 100–109.

$$\zeta_1^1 = ct' - x';\ \zeta_2^2 = ct' + x';\ \zeta_2^1 = y' + iz';\ \zeta_1^2 = y' - iz'$$

should also be real. We shall require also that the determinant of the matrix $\boldsymbol{B}$ be the reciprocal of the determinant of $\boldsymbol{A}$ so that the determinant of ζ will be equal to the determinant of η:

$$(B) \qquad c^2t'^2 - x'^2 - y'^2 - z'^2 = c^2t^2 - x^2 - y^2 - z^2.$$

It is at once apparent that ζ is unaltered if the matrix $\boldsymbol{A}$ is multiplied by a scalar m provided $\boldsymbol{B}$ is multiplied by the reciprocal $1/m$ of the scalar so there is no lack of generality in taking $\boldsymbol{A}$ and $\boldsymbol{B}$ to be matrices whose determinants are unity and we shall suppose this agreed to. The equation (A) is equivalent to the four equations:

$$(C) \qquad \begin{aligned}
\zeta_1^1 &= a_1^1b_1^1\eta_1^1 + a_1^1b_1^2\eta_2^1 + a_2^1b_1^1\eta_1^2 + a_2^1b_1^2\eta_2^2\\
\zeta_2^1 &= a_1^1b_2^1\eta_1^1 + a_1^1b_2^2\eta_2^1 + a_2^1b_2^1\eta_1^2 + a_2^1b_2^2\eta_2^2\\
\zeta_1^2 &= a_1^2b_1^1\eta_1^1 + a_1^2b_1^2\eta_2^1 + a_2^2b_1^1\eta_1^2 + a_2^2b_1^2\eta_2^2\\
\zeta_2^2 &= a_1^2b_2^1\eta_1^1 + a_1^2b_2^2\eta_2^1 + a_2^2b_2^1\eta_1^2 + a_2^2b_2^2\eta_2^2
\end{aligned}$$

and if ζ_1^1, ζ_2^2 are to be real when η_1^1, η_2^2 are real whilst η_2^1, η_1^2 are conjugate imaginaries we must have

$$\begin{aligned}
a_1^1\bar{b}_1^1 &= a_1^1b_1^1;\ a_1^1\bar{b}_1^2 = a_2^1b_1^1;\ a_2^1\bar{b}_1^2 = a_2^1b_1^2\\
a_1^2\bar{b}_2^1 &= a_1^2b_2^1;\ a_1^2\bar{b}_2^2 = a_2^2b_2^1;\ a_2^2\bar{b}_2^2 = a_2^1b_2^2
\end{aligned}$$

which imply

$$b_1^1 = \lambda\bar{a}_1^1;\ b_2^1 = \mu\bar{a}_1^2;\ b_1^2 = \lambda\bar{a}_2^1;\ b_2^2 = \mu\bar{a}_2^2;\ \lambda \text{ and } \mu \textit{ real}.$$

In order that ζ_1^2 may at the same time be the conjugate imaginary to ζ_2^1 it is necessary and sufficient that $\mu = \lambda$ and then the fact that the matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ are of determinant unity gives

$$\lambda^2 = 1 \text{ i.e. } \lambda = \pm 1.$$

We may consider in detail merely the case where $\lambda = 1$, the case $\lambda = -1$ being equivalent to this followed by a change of sign of ζ i.e. of (x', y', z', ct'). Hence our transformation (A) is of the type

$$(D) \qquad \zeta = \boldsymbol{A}\eta\bar{\boldsymbol{A}}'$$

where the prime attached to a matrix signifies the transposed matrix. It follows that to the two matrices $\pm\boldsymbol{A}$ correspond the same transformation from η to ζ. The transformation from (x, y, z, ct) to (x', y', z', ct') induced by (D) is readily found from (C) on writing $b_1^1 = \bar{a}_1^1$; $b_2^1 = \bar{a}_1^2$; $b_1^2 = \bar{a}_2^1$; $b_2^2 = \bar{a}_2^2$ and using the relations

$$2x' = \zeta_2^2 - \zeta_1^1;\ 2ct' = \zeta_2^2 + \zeta_1^1;\ 2y' = \zeta_2^1 + \zeta_1^2;\ 2iz' = \zeta_2^1 - \zeta_1^2.$$

It may be conveniently given by means of the following table:

Table I.

$\downarrow^{\rightarrow}$	x	y	z	ct
x'	$\frac{1}{2}(a_2^2\bar{a}_2^2 - a_2^1\bar{a}_2^1 - a_1^2\bar{a}_1^2 + a_1^1\bar{a}_1^1)$	$\frac{1}{2}(a_1^2\bar{a}_2^2 - a_1^1\bar{a}_2^1 + a_2^2\bar{a}_1^2 - a_2^1\bar{a}_1^1)$	$\frac{1}{2i}(a_1^1\bar{a}_2^1 - a_1^2\bar{a}_2^2 - a_2^1\bar{a}_1^1 + a_2^2\bar{a}_1^2)$	$\frac{1}{2}(a_2^2\bar{a}_2^2 - a_2^1\bar{a}_2^1 + a_1^2\bar{a}_1^2 - a_1^1\bar{a}_1^1)$
y'	$\frac{1}{2}(a_2^2\bar{a}_2^1 + a_2^1\bar{a}_2^2 - a_1^2\bar{a}_1^1 - a_1^1\bar{a}_1^2)$	$\frac{1}{2}(a_1^2\bar{a}_2^1 + a_1'\bar{a}_2^2 + a_2^2\bar{a}_1^1 + a_2^1\bar{a}_1^2)$	$\frac{1}{2i}(a_2^2\bar{a}_1^1 - a_1^1\bar{a}_2^2 + a_2^1\bar{a}_1^2 - a_1^2\bar{a}_2^1)$	$\frac{1}{2}(a_2^2\bar{a}_2^1 + a_2^1\bar{a}_2^2 + a_1^2\bar{a}_1^1 + a_1^1\bar{a}_1^2)$
z'	$\frac{1}{2i}(a_2^1\bar{a}_2^2 - a_2^2\bar{a}_2^1 + a_1^2\bar{a}_1^1 - a_1^1\bar{a}_1^2)$	$\frac{1}{2i}(a_1^1\bar{a}_2^2 - a_1^2\bar{a}_2^1 - a_2^2\bar{a}_1^1 + a_2^1\bar{a}_1^2)$	$\frac{1}{2}(a_1^1\bar{a}_2^2 - a_1^2\bar{a}_2^1 + a_2^2\bar{a}_1^1 - a_2^1\bar{a}_1^2)$	$\frac{1}{2i}(a_2^1\bar{a}_2^2 - a_2^2\bar{a}_2^1 - a_1^2\bar{a}_1^1 + a_1^1\bar{a}_1^2)$
ct'	$\frac{1}{2}(a_2^2\bar{a}_2^2 + a_2^1\bar{a}_2^1 - a_1^2\bar{a}_1^2 - a_1^1\bar{a}_1^1)$	$\frac{1}{2}(a_1^2\bar{a}_2^2 + a_1^1\bar{a}_2^1 + a_2^2\bar{a}_1^2 + a_2^1\bar{a}_1^1)$	$\frac{1}{2i}(a_2^2\bar{a}_1^2 - a_1^2\bar{a}_2^2 + a_2^1\bar{a}_1^1 - a_1^1\bar{a}_2^1)$	$\frac{1}{2}(a_2^2\bar{a}_2^2 + a_2^1\bar{a}_2^1 + a_1^2\bar{a}_1^2 + a_1^1\bar{a}_1^1)$

This table furnishes us with a parametric representation of the sixteen coefficients of those real homogeneous linear transformations from (x, y, z, ct) to (x', y', z', ct') for which $c^2t'^2-x'^2-y'^2-z'^2$ is equal to $c^2t^2-x^2-y^2-z^2$. These are called Lorentz transformations and the representation is in terms of 4 complex parameters $(a_1^1, a_2^1, a_1^2, a_2^2)$ which are connected by the relation $a_1^1a_2^2-a_2^1a_1^2=1$; in other words three of the complex parameters are arbitrary so that six real independent parameters are involved. A particular case of interest arises when the transforming matrix $\boldsymbol{A}$, of determinant unity, is such that $\bar{\boldsymbol{A}}'=\boldsymbol{A}^{-1}$. In this case $\boldsymbol{A}$ is said to be *unitary*, and we shall denote it by $\boldsymbol{U}$. Since

$$\boldsymbol{A}^{-1} = \begin{Vmatrix} a_2^2 & -a_2^1 \\ -a_1^2 & a_1^1 \end{Vmatrix}$$

it follows that $u_2^2=\bar{u}_1^1$; $u_1^2=-\bar{u}_2^1$ and our table reduces to

Table II.

$\downarrow^{\rightarrow}$	x	y	z	ct
x'	$(u_1^1\bar{u}_1^1 - u_2^1\bar{u}_2^1)$	$-(u_1^1\bar{u}_2^1 + \bar{u}_1^1u_2^1)$	$i(u_2^1\bar{u}_1^1 - u_1^1\bar{u}_2^1)$	0
y'	$(u_1^1u_2^1 + \bar{u}_1^1\bar{u}_2^1)$	$\frac{1}{2}(u_1^{1^2} + \bar{u}_1^{1^2} - u_2^{1^2} - \bar{u}_2^{1^2})$	$\frac{1}{2i}(\bar{u}_1^{1^2} - u_1^{1^2} + \bar{u}_2^{1^2} - u_2^{1^2})$	0
z'	$i(\bar{u}_1^1\bar{u}_2^1 - u_1^1u_2^1)$	$\frac{1}{2i}(u_1^{1^2} - \bar{u}_1^{1^2} + \bar{u}_2^{1^2} - u_2^{1^2})$	$\frac{1}{2}(\bar{u}_2^{1^2} + u_2^{1^2} + u_1^{1^2} + \bar{u}_1^{1^2})$	0
ct'	0	0	0	1

(The fact that $ct'=ct$ is a consequence of the transformation

$$(E) \qquad \zeta' = \boldsymbol{U}\eta\boldsymbol{U}^{-1}$$

is obvious without calculation since under such a transformation the first invariant or trace $\eta_\alpha^\alpha \equiv \eta_1^1+\eta_2^2$ is invariant, i.e.

$$\zeta_{\alpha}^{\alpha} = u_{\beta}^{\alpha}\eta_{\delta}^{\beta}u^{-1\delta}_{\ \ \alpha} = (u_{\beta}^{\alpha}u^{-1\delta}_{\ \ \alpha})\eta_{\delta}^{\beta} = \eta_{\beta}^{\beta}).$$

This table gives a parametric representation of the nine coefficients of those real homogeneous linear transformations from (x, y, z) to (x', y', z') for which $x'^2+y'^2+z'^2=x^2+y^2+z^2$ i.e. of the real orthogonal transformations on three variables. The representation is in terms of two complex parameters (u_1^1, u_2^1) connected by the relation $u_1^1\bar{u}_1^1+u_2^1\bar{u}_2^1=1$ so that three real parameters are involved. On writing $u_1^1=\rho+i\lambda$; $u_2^1=-\nu+i\mu$ we secure the usual parametric representation of Rodrigues.[3]

If we write out explicitly the equation (D) we have

$$\zeta_{q}^{p} = a_{\alpha}^{p}\eta_{\beta}^{\alpha}\bar{a}'^{\beta}_{q}$$

and we may, if we wish, regard η_q^p as a (new kind of) mixed tensor of the second rank. If $\boldsymbol{A}$ is a real unitary matrix the definition is equivalent to the usual definition of elementary vector analysis. The general law of transformation of the new class of tensors is put sufficiently in evidence by the example:

$$\zeta_{rst}^{pq} = a_{\alpha}^{p}a_{\beta}^{q}\eta_{\gamma\delta\epsilon}^{\alpha\beta}\bar{a}'^{\gamma}_{r}\bar{a}'^{\delta}_{s}\bar{a}'^{\epsilon}_{t}$$

which is the law of transformation for a tensor which is contravariant of rank two and covariant of rank three. The tensors of rank one (or vectors) are now pairs of complex numbers which are transformed according to the formulae

$$\zeta^{p} = a_{\alpha}^{p}\eta^{\alpha}\ ;\ \zeta_{p} = \bar{a}'^{\alpha}_{p}\eta_{\alpha}$$

and these vectors are called spin-vectors. As we have seen, the ordinary four-vector, (x, y, z, ct) is derivable from a mixed spin-tensor of the second rank.

Canonical Form of the Lorentz Transformation

It is evident from Table I that when $a_2^1=0$, $a_1^2=0$ the transformation from (x, y, z, ct) to the variables (x', y', z', ct') takes a very simple form. Since the determinant of $\boldsymbol{A}$ is unity $a_2^2=1/a_1^1$ and if we set $a_1^1\bar{a}_1^1=\bar{e}^{\theta}$; $\bar{a}_1^1/a_1^1=e^{i\phi}$ (so that θ and ϕ are real) we find

$$(F)\qquad \begin{aligned} x' &= \cosh\theta\ x + \sinh\theta\ ct;\ \ y' = \ \ \cos\phi\ \ y + \sin\phi\ \ z \\ ct' &= \sinh\theta\ x + \cosh\theta\ ct;\ \ z' = -\sin\phi\ \ y + \cos\phi\ \ z. \end{aligned}$$

This is a transformation of coordinates due to a rotation of the (y, z) axes through an angle ϕ in their plane together with a (pseudo) rotation of the (x, ct) axes through an angle θ in their plane.

The general transformation (D) may be reduced to the simple case just discussed as follows. From $\zeta=\boldsymbol{A}\eta\bar{\boldsymbol{A}}'$ we have $\boldsymbol{B}\zeta\bar{\boldsymbol{B}}'=\boldsymbol{BAB}^{-1}.\boldsymbol{B}\eta\bar{\boldsymbol{B}}'.\bar{\boldsymbol{B}}'^{-1}\boldsymbol{A}'\bar{\boldsymbol{B}}'$ or

[3] Cf. Ames and Murnaghan, *Theoretical Mechanics*, p. 79 or L. E. Dickson, *Modern Algebraic Theories*, p. 100.

$$(D') \qquad \zeta_* = A_*\eta_*A_*'$$

where $\eta_* = B\eta\bar{B}'$; $\zeta_* = B\zeta\bar{B}'$; $A_* = BAB^{-1}$ and B has its determinant unity. The transformations from η to η_* and from ζ to ζ_* are the same Lorentz Transformation and (D') may be interpreted as the same transformation as (D) referred to new axes of coordinates. It is now merely necessary to show that a matrix B can, save in one exceptional case, be found so that $a_{*2}{}^1 = 0$, $a_{*1}{}^2 = 0$. Instead of calling upon the general theory of similar matrices[4] it is more useful for us to actually construct the transforming matrix B. Since the determinant of B is unity we have

$$B^{-1} = \begin{Vmatrix} b_2{}^2 & -b_2{}^1 \\ -b_1{}^2 & b_1{}^1 \end{Vmatrix}$$

and a glance at the equations (C) tells us that in order that $A_* = BAB^{-1}$ may have its elements $a_{*2}{}^1$, $a_{*1}{}^2$ equal to zero the ratio of $b_1{}^1$ to $b_2{}^1$ and of $b_1{}^2$ to $b_2{}^2$ must be roots of the quadratic equation

$$a_2{}^1\xi^2 + (a_2{}^2 - a_1{}^1)\xi - a_1{}^2 = 0.$$

Remembering that $a_1{}^1a_2{}^2 - a_2{}^1a_1{}^2 = 1$ the roots of this equation appear as

$$(\xi_1, \xi_2) = [(a_1{}^1 - a_2{}^2) \pm (I^2 - 4)^{1/2}]/2a_2{}^1,$$

where $I = a_1{}^1 + a_2{}^2$. Since the determinant of B is to be unity these two roots must be distinct so that, save for the exceptional cases where $I = \pm 2$, A can be reduced to the form A_*, with $a_{*2}{}^1 = 0$, $a_{*1}{}^2 = 0$ by means of the matrix B:

$$B = \begin{Vmatrix} \xi_1 b_2{}^1 & b_2{}^1 \\ \xi_2 b_2{}^2 & b_2{}^2 \end{Vmatrix}$$

where $(\xi_1 - \xi_2)b_2{}^1 b_2{}^2 = 1$. An easy calculation gives

$$a_{*1}{}^1 + a_{*2}{}^2 = I; \quad a_{*1}{}^1 a_{*2}{}^2 = 1$$

(results which are evident without calculation since both I and the determinant of A are invariant under the transformation $A_* = BAB^{-1}$). Hence $a_{*1}{}^1$ and $a_{*2}{}^2$ are the two roots of the quadratic equation $w^2 - Iw + 1 = 0$.

The four quantities $a_{*1}{}^1\bar{a}_{*1}{}^1$, $a_{*1}{}^1\bar{a}_{*2}{}^2$, $\bar{a}_{*1}{}^1 a_{*2}{}^2$, $a_{*2}{}^2\bar{a}_{*2}{}^2$ satisfy, therefore, the quartic equation whose roots are the four products of a root of $w^2 - Iw + 1 = 0$ by a root of $v^2 - \bar{I}v + 1 = 0$. Eliminating w and v between these two equations and the equation $\lambda = wv$ we obtain

$$(G) \qquad \lambda^4 - \lambda^3(I\bar{I}) + \lambda^2(I^2 + \bar{I}^2 - 2) - \lambda(I\bar{I}) + 1 = 0.$$

The four roots of this reciprocal equation are readily obtained by setting $\lambda + \lambda^{-1} = 2\mu$ when we find

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[4] Cf. L. E. Dickson, *Modern Algebraic Theories*, p. 104.

$$(H) \qquad (\mu_1, \mu_2) = \tfrac{1}{4}[I\bar{I} \pm (I^2 - 4)^{1/2}(\bar{I}^2 - 4)^{1/2}]$$

so that μ_1 and μ_2 are real. If we mark in an auxiliary complex plane the points $(0, I^2, 4)$ and denote the lengths of the sides of the resulting triangle by (a, b, c) we have $(\mu_1, \mu_2) = (c \pm a)/b$ so that one of the values $\mu_1 \geqq 1$ whilst μ_2 has its numerical value less than or equal to 1. We may, therefore, set $\mu_1 = \cosh \theta$ $\mu_2 = \cos \phi (\theta, \phi$ real) and the four values of λ are

$$\lambda_1 = e^{-\theta}, \quad \lambda_2 = e^{+\theta}; \quad \lambda_3 = e^{-i\phi}, \quad \lambda_4 = e^{+i\phi}.$$

(When I is real two of these values coincide with the common value unity; when the absolute value of I is less than 2 we have $\lambda_1 = \lambda_2 = 1$, i.e., $\theta = 0$ and when the absolute value of I is greater than 2 we have $\lambda_3 = \lambda_4 = 1$, i.e. $\phi = 0$). It follows that the Lorentz transformation appears in the canonical form (F) with (x_*, y_*, z_*, ct_*) written for (x, y, z, ct) and $(x_*', y_*', z_*', ct_*')$ for (x', y', z', ct').

The equation (G) arises in another connection which throws considerable light on the results already obtained. Let us ask if there exists a matrix η which is transformed by a given matrix $\boldsymbol{A}$ (in accordance with the law of transformation D) into a scalar multiple of itself i.e. $\zeta = \lambda\eta$ or

$$(I) \qquad \lambda\eta = \boldsymbol{A}\eta\bar{\boldsymbol{A}}'.$$

The four equivalent homogeneous equations in the quantities $(\eta_1^1, \eta_2^1, \eta_1^2, \eta_2^2)$ must have the determinant of their coefficients zero and so we obtain what may be called the *proper* or characteristic equation of the matrix $\boldsymbol{A}$:

$$(J) \qquad \begin{vmatrix} a_1^1\bar{a}_1^1 - \lambda & a_1^1\bar{a}_2^1 & a_2^1\bar{a}_1^1 & a_2^1\bar{a}_2^1 \\ a_1^1\bar{a}_1^2 & a_1^1\bar{a}_2^2 - \lambda & a_2^1\bar{a}_1^2 & a_2^1\bar{a}_2^2 \\ a_1^2\bar{a}_1^1 & a_1^2\bar{a}_2^1 & a_2^2\bar{a}_1^1 - \lambda & a_2^2\bar{a}_2^1 \\ a_1^2\bar{a}_1^2 & a_1^2\bar{a}_2^2 & a_2^2\bar{a}_1^2 & a_2^2\bar{a}_2^2 - \lambda \end{vmatrix} = 0.$$

Denoting as before by I the first invariant or trace of the matrix $\boldsymbol{A}$

$$I = a_1^1 + a_2^2$$

the proper equation[5] is (on remembering that the determinant of $\boldsymbol{A}$ is unity)

$$\lambda^4 - \lambda^3(I\bar{I}) + \lambda^2(I^2 + \bar{I}^2 - 2) - \lambda I\bar{I} + 1 = 0$$

It follows at once from (I) that $\lambda\eta_* = \boldsymbol{A}_*\eta_*\bar{\boldsymbol{A}}'_*$ where $\boldsymbol{A}_* = \boldsymbol{BAB}^{-1}$, $\eta_* = \boldsymbol{B}\eta\bar{\boldsymbol{B}}'$ so that λ is also a proper number of the *similar* matrix $\boldsymbol{A}_*$, the corresponding proper matrix being obtained from η by a transformation of type (D). If the transforming matrix $\boldsymbol{B}$ is so chosen that $a_{*2}^1 = 0$, $a_{*1}^2 = 0$ (which can always be

[5] This definition of the proper-values (eigenwerte) of a matrix $\boldsymbol{A}$ is interesting because it is given without leaving the field of square matrices. The usual definition involves the introduction of vectors i.e. matrices of one column. Thus instead of (A) we have $\boldsymbol{Ax} = \boldsymbol{y}$ (explicitly, $a_\alpha^r x^\alpha = y^r$) and the proper numbers are those for which $\boldsymbol{y} = \lambda\boldsymbol{x}$.

done by a matrix $\boldsymbol{B}$ of determinant unity proved the invariant I of $\boldsymbol{A}$ is different from ± 2) the equation $\lambda\eta_* = \boldsymbol{A}_*\eta_*\bar{\boldsymbol{A}}_*'$ is equivalent to the equations

$$\lambda\eta_{*1}{}^1 = a_{*1}{}^1\bar{a}_{*1}{}^1\eta_{*1}{}^1;\ \lambda\eta_{*2}{}^1 = a_{*1}{}^1\bar{a}_{*2}{}^2\eta_{*2}{}^1;\ \lambda\eta_{*1}{}^2 = a_{*2}{}^2\bar{a}_{*1}{}^1\eta_{*1}{}^2;\ \lambda\eta_{*2}{}^2 = a_{*2}{}^2\bar{a}_{*2}{}^2\eta_{*2}{}^2$$

so that the four proper numbers are $\lambda_1 = a_{*1}{}^1\bar{a}_{*1}{}^1 = \bar{e}^{\theta}$; $\lambda_2 = a_{*2}{}^2\bar{a}_{*2}{}^2 = e^{\theta}$; $\lambda_3 = a_{*2}{}^2\bar{a}_{*1}{}^1 = e^{i\psi}$; $\lambda_4 = a_{*1}{}^1\bar{a}^*{}_2{}^2 = e^{-i\psi}$ (since the determinant of $\boldsymbol{A}_*$ is unity $a_{*2}{}^2 = 1/a_{*1}$). The corresponding proper matrices are

$$\eta_*{}^1 = \left\|\begin{matrix} 1 & 0 \\ 0 & 0 \end{matrix}\right\|;\ \eta_*{}^2 = \left\|\begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix}\right\|;\ \eta_*{}^3 = \left\|\begin{matrix} 0 & 0 \\ 1 & 0 \end{matrix}\right\|;\ \eta_*{}^4 = \left\|\begin{matrix} 0 & 1 \\ 0 & 0 \end{matrix}\right\|.$$

An arbitrary matrix

$$\eta_* = \left\|\begin{matrix} \eta_{*1}{}^1 & \eta_{*2}{}^1 \\ \eta_{*1}{}^2 & \eta_{*2}{}^2 \end{matrix}\right\|$$

may be written in the form

$$\eta_* = \eta_{*1}{}^1\eta_*{}^1 + \eta_{*2}{}^2\eta_*{}^2 + \eta_{*1}{}^2\eta_*{}^3 + \eta_{*2}{}^1\eta_*{}^4$$

and when this is transformed by the matrix $\boldsymbol{A}$, in accordance with (D), we have

$$\zeta_* = \lambda_1\eta_{*1}{}^1\eta_*{}^1 + \lambda_2\eta_{*2}{}^2\eta_*{}^2 + \lambda_3\eta_{*1}{}^3\eta_*{}^2 + \lambda_4\eta_{*2}{}^1\eta_*{}^4$$

or explicitly,

$$\zeta_{*1}{}^1 = \lambda_1\eta_{*1}{}^1\ ;\ \zeta_{*2}{}^2 = \lambda_2\eta_{*2}{}^2\ ;\ \zeta_{*2}{}^1 = \lambda_4\eta_{*2}{}^1\ ;\ \zeta_{*1}{}^2 = \lambda_3\eta_{*1}{}^2$$

These equations are equivalent to the equations (F) with (x_*, y_*, z_*, ct_*) written for (x, y, z, ct) and (x_*', y_*', z_*', ct') for (x', y', z', ct').

The Special Lorentz Transformations for which $I = \pm 2$.

When the invariant $I = a_1{}^1 + a_2{}^2$ of the matrix $\boldsymbol{A}$ has either of the values ± 2 it is not possible to find a matrix $\boldsymbol{B}$ of determinant unity such that the matrix $\boldsymbol{A}_* = \boldsymbol{BAB}^{-1}$ has both the elements $a_{*2}{}^1$, $a_{*1}{}^2$ equal to zero. Assuming that $a_2{}^1$ is not zero it is merely necessary to have $b_1{}^1 : b_2{}^1 = a_1{}^1 - a_2{}^2 : 2a_2{}^1$ in order that $a_{*2}{}^1 = 0$. Since $a_{*1}{}^1 + a_{*2}{}^2 = \pm 2$ and $a_{*1}{}^1 a_{*2}{}^2 = 1$ we have $a_{*1}{}^1 = \pm 1$; $a_{*2}{}^2 = \pm 1$ (it is sufficient to consider the case $I = 2$ since the same Lorentz transformation is furnished by the two matrices $\pm\boldsymbol{A}$). Hence $a_{*1}{}^1 = 1$; $a_{*2}{}^2 = 1$ and if $a_{*1}{}^2$ were zero $\boldsymbol{A}$ would be the unit matrix $\boldsymbol{E}$ so that we would have $\boldsymbol{BAB}^{-1} = \boldsymbol{E}$ i.e. $\boldsymbol{BA} = \boldsymbol{B}$ necessitating $\boldsymbol{B} = \boldsymbol{E}$. Hence the Lorentz transformations for which $I = \pm 2$ cannot be put in the canonical form (F) unless the transformation in question is the identity. When $\boldsymbol{A} = \boldsymbol{U}$ is unitary, so that the Lorentz transformation leaves t invariant, and $I = 2$ it follows from $u_2{}^2 = \bar{u}_1{}^1$; $u_1{}^2 = -\bar{u}_2{}^1$, $u_2{}^2 = 2 - u_1{}^1$, $u_1{}^1u_2{}^2 - u_2{}^1u_1{}^2 = 1$ that $\boldsymbol{U} = \boldsymbol{E}$ (for $u_2{}^1\bar{u}_2{}^1 = (1 - u_1{}^1)^2$ so that $u_1{}^1$ is real and therefore $= u_2{}^2$ so that $u_1{}^1 = u_2{}^2 = 1$ and $u_2{}^1 = 0 = u_1{}^2$). Hence there are no such unitary matrices, with determinant unity, other than the identity. This is not, however, the case for non-unitary matrices of order two. It is possible,

when $I=2$, to find axes of coordinates for which $a_{*2}^{1}=0$ and $a_{*1}^{2}=\epsilon$ is of arbitrarily small modulus but nevertheless it is impossible to make $\epsilon=0$. The following canonical form for the special Lorentz transformations, other than the identity, for which $I=2$ corresponds to $a_{*2}^{1}=0$, $a_{*1}^{2}=\epsilon$

$$(K)\qquad \begin{aligned} x' &= x+\tfrac{1}{2}(\epsilon+\bar{\epsilon})y+\tfrac{1}{2}(\epsilon-\bar{\epsilon})iz+\tfrac{1}{2}\epsilon\bar{\epsilon}(ct-x)\\ y' &= \qquad y \qquad\qquad +\tfrac{1}{2}(\epsilon+\bar{\epsilon})(ct-x)\\ z' &= \qquad z \qquad\qquad +\tfrac{1}{2}i(\epsilon-\bar{\epsilon})(ct-x)\\ ct' &= \tfrac{1}{2}\epsilon\bar{\epsilon}(ct-x)+\tfrac{1}{2}(\epsilon+\epsilon)y+\tfrac{1}{2}(\epsilon-\bar{\epsilon})iz+ct \end{aligned}$$

It is clear that $ct'-x'=ct-x$; $(\epsilon+\bar{\epsilon})z'-i(\epsilon-\bar{\epsilon})y'=(\epsilon+\bar{\epsilon})z-i(\epsilon-\bar{\epsilon})y$. The four characteristic numbers λ are all unity and the characteristic matrices are of the type

$$\begin{Vmatrix} 0 & -\bar{\epsilon} \\ \epsilon & \eta_{*2}^{2} \end{Vmatrix}$$

where η_{*2}^{2} is arbitrary.

SMALL OSCILLATIONS OF THE NEUTRAL HELIUM ATOM NEAR THE EQUILATERAL TRIANGLE POSITIONS

By H. E. BUCHANAN, Tulane University

Introduction. Various papers[1] have been published in recent years on the neutral helium atom considered from the standpoint of the classical mechanics. In all of them, except in Professor Crudeli's paper, the masses of the negatively charged electrons are considered to be infinitesimal compared to the mass of the nucleus. Professor Crudeli neglects the mutual attraction due to gravitation and in the last few paragraphs of his work he makes the mass of the central nucleus approach infinity in order to obtain a simplified form of his characteristic equation. His treatment of the complex algebra is very remarkable.

This paper treats the same problem that Professor Crudeli treated. It obtains all of his and the following new results:

1. The center of gravity integrals are used to reduce the order of the differential equations and the resulting degree of the characteristic equation is lowered from the eighteenth to the twelfth.

2. Certain checks are provided which insure the accuracy of the algebraic manipulations. These checks were lacking in Professor Crudeli's paper but his results are correct.

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[1] [Rawles, Bulletin of the American Mathematical Society, vol. 34 (1928), pp. 618 to 630; Van Vleck, Bulletin of the National Research Council, vol. 10, part 4, (1926), Chapter 7; D. Buchanan, Transactions of the Royal Society of Canada, Series 3, vol. 23 (1929), pp. 227 to 245; U. Crudeli, Rendiconti Del Circolo Matematico Di Palermo, vol. 51 (1926), pp. 1 to 20; Langmuir, Physical Review, vol. 17 (1921), pp. 339 to 353.]

3. The characteristic exponents are found for finite values of the masses, a complete discussion of the nature of the small oscillations is given and certain new theorems proved.

The Differential Equations. Let the mass of the nucleus be m_1 and the masses of the electrons be m_2 and m_3 respectively. We assume a positive charge of e_1 on m_1 and negative charges of e_2 and e_3 on m_2 and m_3. We neglect the gravitational attraction between the masses. Assuming Coulomb's law and using axes rotating uniformly in the $\xi\eta$ plane we have

$$\begin{aligned}
&\frac{d^2\xi_i}{dt^2} - 2\omega\frac{d\eta_i}{dt} - \omega^2\xi_i + \frac{k^2}{m_i}\frac{\partial U}{\partial \xi_i} = 0,\\
&\frac{d^2\eta_i}{dt^2} + 2\omega\frac{d\xi_i}{dt} - \omega^2\eta_i + \frac{k^2}{m_i}\frac{\partial U}{\partial \eta_i} = 0,\\
&\frac{d^2\zeta_i}{dt^2} + \frac{k^2}{m_i}\frac{\partial U}{\partial \zeta_i} = 0, \quad i = 1, 2, 3,
\end{aligned} \tag{1}$$

where ω is the angular velocity and where

$$U = \frac{e_1e_2}{r_{12}} + \frac{e_1e_3}{r_{13}} - \frac{e_2e_3}{r_{23}}.$$

The Equilateral Triangle Solutions. We seek for a solution of equations (1) in which the three bodies remain at the vertices of an equilateral triangle and rotate in circles. In this event ξ_i, η_i and ζ_i are constants and their derivatives are zero. We choose $r_{ij} = 1$. Such solutions exist if we can satisfy simultaneously the equations:

$$\begin{cases}
-m_1\omega^2\xi_1 + k^2e_1e_2(\xi_1 - \xi_2) + k^2e_1e_3(\xi_1 - \xi_3) = 0,\\
-m_2\omega^2\xi_2 + k^2e_1e_2(\xi_2 - \xi_1) - k^2e_2e_3(\xi_2 - \xi_3) = 0,\\
-m_3\omega^2\xi_3 + k^2e_1e_3(\xi_3 - \xi_1) - k^2e_2e_3(\xi_3 - \xi_2) = 0,
\end{cases} \tag{2}$$

$$\begin{cases}
-m_1\omega^2\eta_1 + k^2e_1e_2(\eta_1 - \eta_2) + k^2e_1e_3(\eta_1 - \eta_3) = 0,\\
-m_2\omega^2\eta_2 + k^2e_1e_2(\eta_2 - \eta_1) - k^2e_2e_3(\eta_2 - \eta_3) = 0,\\
-m_3\omega^2\eta_3 + k^2e_1e_3(\eta_3 - \eta_1) - k^2e_2e_3(\eta_3 - \eta_2) = 0,
\end{cases} \tag{3}$$

$$\begin{aligned}
&e_2(\zeta_1 - \zeta_2) + e_3(\zeta_1 - \zeta_3) = 0,\\
&e_1(\zeta_2 - \zeta_1) - e_3(\zeta_2 - \zeta_3) = 0,\\
&e_1(\zeta_3 - \zeta_1) - e_2(\zeta_3 - \zeta_2) = 0.
\end{aligned} \tag{4}$$

Consider first the equations (2). One solution is $\xi_1 = \xi_2 = \xi_3 = 0$. In order that there may be any other solution we must have

$$\begin{vmatrix} -m_1\omega^2 + k^2(e_1e_2 + e_1e_3), & -k^2e_1e_2, & -k^2e_1e_3 \\ -k^2e_1e_2, & -m_2\omega^2 + k^2(e_1e_2 - e_2e_3), & k^2e_2e_3 \\ -k^2e_1e_3, & k^2e_2e_3, & -m_3\omega^2 + k^2(e_1e_3 - e_2e_3) \end{vmatrix} = 0.$$

Now if we make $m_2 = m_3 = m$ and $2e = e_1 = 2e_2 = 2e_3$, replace the first column by the sum of all the columns, and remove the common factor ω^2 we shall have

$$\begin{vmatrix} m_1 & 2k^2e^2 & 2k^2e^2 \\ m & m\omega^2 - k^2e^2 & -k^2e^2 \\ m & -k^2e^2 & m\omega^2 - k^2e^2 \end{vmatrix} = 0.$$

The solution of this equation is

$$\omega^2 = 2k^2e^2(2m + m_1)/mm_1.$$

The values of ξ_1 and ξ_2 in terms of ξ_3 may be found from any two of equations (2). They are

$$\xi_2 = \xi_3 \text{ and } \xi_1 = -2m\xi_3/\eta_1.$$

Equations (3) can be solved in exactly the same way as equations (2) and the result is obviously the same. It is simpler however to satisfy equations (3), by $\eta_1 = \eta_2 = \eta_3 = 0$. The ζ_i equations can be satisfied by

$$\zeta_1 = 0, \quad \zeta_2 = -\zeta_3 = \tfrac{1}{2}.$$

Thus it appears that in order that the circular equilateral triangle solutions exist it is necessary that the plane of the triangle be the $\xi\zeta$ plane and that the rotation be around the ζ axis. This is equivalent to saying that the electrons and the nucleus move in parallel circles, and the line joining the centers of these circles is perpendicular to their planes.

The Integrals of Equations. (1). The usual methods of celestial mechanics may be applied to equations (1) since U is unchanged by shifting or by rotating the axes. Hence the ten integrals of the celestial mechanics exist. In particular the center of gravity integrals become

$$m_1\xi_1 + m(\xi_2 + \xi_3) = 0, \text{ or } \xi_2 = -\frac{m_1\xi_1}{m} - \xi_3,$$

$$m_1\eta_1 + m(\eta_2 + \eta_3) = 0, \text{ or } \eta_2 = -\frac{m_1\eta_1}{m} - \eta_3,$$

$$m_1\zeta_1 + m(\zeta_2 + \zeta_3) = 0, \text{ or } \zeta_2 = -\frac{m_1\zeta_1}{m} - \zeta_3.$$

The Equations for Small Oscillations. We call the coordinates in the equilateral triangle positions $(\xi_i^{(0)}, 0, \zeta_i^{(0)})$, ζ_1^0 being zero, and make the transformation

$$\xi_i = \xi_i^{(0)} + x_i, \quad \eta_i = y_i, \quad \zeta_i = \zeta_i^{(0)} + z_i.$$

We eliminate x_2, y_2, z_2 wherever they occur by the center of gravity equations. Then equations (1) become:

$$\frac{d^2x_1}{dt^2} - 2\omega\frac{dy_1}{dt} = \omega^2(\xi_1^{(0)} + x_1) - \frac{k^2e^2}{m_1}\left\{\frac{2(\xi_1^{(0)} + x_1 - \xi_2^{(0)} - x_2)}{r_{12}} + \frac{2(\xi_1^{(0)} + x_1 - \xi_3^{(0)} - x_3)}{r_{13}^3}\right\},$$

$$\frac{d^2x_3}{dt^2} - 2\omega\frac{dy_3}{dt} = \omega^2(\xi_3^{(0)} + x_3) - \frac{k^2e^2}{m}\left\{\frac{2(\xi_3^{(0)} + x_3 - \xi_1^{(0)} - x_1)}{r_{13}^3} - \frac{(\xi_3^{(0)} + x_3 - \xi_2^{(0)} - x_2)}{r_2^3}\right\},$$

$$\text{(5)}\quad \frac{d^2y_1}{dt^2} + 2\omega\frac{dx_1}{dt} = \omega^2 y_1 - \frac{2k^2e^2}{m_1}\left\{\frac{y_1 - y_2}{r_{12}^3} + \frac{y_1 - y_3}{r_{13}^3}\right\},$$

$$\frac{d^2y_3}{dt^2} + 2\omega\frac{dx_3}{dt} = \omega^2 y_3 - \frac{k^2e^2}{m}\left\{\frac{2(y_3 - y_1)}{r_{13}^3} - \frac{y_3 - y_2}{r_{23}^3}\right\},$$

$$\frac{d^2z_1}{dt^2} = -\frac{2k^2e^2}{m_1}\left\{\frac{z_1 - \zeta_2^{(0)} - z_2}{r_{12}^3} + \frac{z_1 - \zeta_3^{(0)} - z_3}{r_{13}^3}\right\},$$

$$\frac{d^2z_3}{dt^2} = -\frac{k^2e^2}{m}\left\{\frac{2(\zeta_3^{(0)} + z_3 - z_1)}{r_{13}^3} - \frac{\zeta_3^{(0)} + z_3 - \zeta_2^{(0)} - z_2}{r_{23}^3}\right\}.$$

We expand the right members into power series in x_i, y_i, z_i, $i = 1, 3$. When only the linear terms in these series are considered we have the following system:

$$\frac{d^2x_1}{dt^2} - 2\omega\frac{dy_1}{dt} = A_{11}x_1 + A_{13}x_3 + B_{11}y_1 + B_{13}y_3 + C_{11}z_1 + C_{13}z_3,$$

$$\frac{d^2x_3}{dt^2} - 2\omega\frac{dy_3}{dt} = A_{21}x_1 + A_{23}x_3 + B_{21}y_1 + B_{23}y_3 + C_{21}z_1 + C_{23}z_3,$$

$$\frac{d^2y_1}{dt^2} + 2\omega\frac{dx_1}{dt} = A_{31}x_1 + A_{33}x_3 + B_{31}y_1 + B_{33}y_3 + C_{31}z_1 + C_{33}z_3,$$

$$\text{(6)}\quad \frac{d^2y_3}{dt^2} + 2\omega\frac{dx_3}{dt} = A_{41}x_1 + A_{43}x_3 + B_{41}y_1 + B_{43}y_3 + C_{41}z_1 + C_{43}z_3,$$

$$\frac{d^2z_1}{dt^2} = A_{51}x_1 + A_{53}x_3 + B_{51}y_1 + B_{53}y_3 + C_{51}z_1 + C_{53}z_3,$$

$$\frac{d^2z_3}{dt^2} = A_{61}x_1 + A_{63}x_3 + B_{61}y_1 + B_{63}y_3 + C_{61}z_1 + C_{63}z_3,$$

where

$$A_{11} = \frac{9}{4}\omega^2,\ A_{13} = 0,\ B_{11} = 0,\ B_{13} = 0,$$

$$C_{11} = \frac{-3\sqrt{3}\cdot k^2e^2}{2m},\ C_{13} = -\frac{3\sqrt{3}\cdot k^2e^2}{m_1},$$

$$A_{21} = -\frac{k^2e^2(5m-2m_1)}{2m^2},\ A_{23} = \omega^2 + \frac{9k^2e^2}{2m},$$

$$B_{21} = 0,\ B_{23} = 0,\ C_{21} = \frac{-3\sqrt{3}\cdot k^2e^2}{2m},\ C_{23} = \frac{3\sqrt{3}\cdot k^2e^2}{2m},$$

$$A_{31} = 0,\ A_{33} = 0,\ B_{31} = 0,\ B_{33} = 0,\ C_{31} = 0,\ C_{33} = 0,$$

$$A_{41} = 0,\ A_{43} = 0,\ B_{41} = \frac{m_1\omega^2}{2m},\ B_{43} = \omega^2,\ C_{41} = 0,\ C_{43} = 0,$$

$$A_{51} = \frac{-3\sqrt{3}\cdot k^2e^2}{2m},\ A_{53} = \frac{-3\sqrt{3}\cdot k^2e^2}{m_1},\ B_{51} = 0,\ B_{53} = 0,$$

$$C_{51} = -\tfrac{1}{4}\omega^2,\ C_{53} = 0,\ A_{61} = \frac{3\sqrt{3}\cdot k^2e^2}{2m},\ A_{63} = \frac{-3\sqrt{3}\cdot k^2e^2}{2m}$$

$$B_{61} = 0,\ B_{63} = 0,\ C_{61} = \frac{-k^2e^2(4m_1-m)}{2m^2},\ C_{63} = \frac{-9k^2e^2}{2m}.$$

The Characteristic Equation. The solution of the system (6) is found by substituting

$$x_i = K_ie^{\lambda t},\ y_i = L_ie^{\lambda t},\ z_i = M_ie^{\lambda t},\ i = 1, 3.$$

In order that there shall be any solution different from

$$K_i = L_i = M_i = 0,\quad i = 1, 3,$$

it is necessary that equations (7) shall hold.

$$(7)\quad \begin{vmatrix} -\lambda^2 + \frac{9\omega^2}{4} & 0 & 2\omega\lambda & 0 & \frac{-3\sqrt{3}\cdot k^2e^2}{2m} & \frac{-3\sqrt{3}\cdot k^2e^2}{m_1} \\ \frac{-k^2e^2(5m-2m_1)}{2m^2} & -\lambda^2 + \omega^2 + \frac{9k^2e^2}{2m} & 0 & 2\omega\lambda & \frac{-3\sqrt{3}\cdot k^2e^2}{2m} & \frac{3\sqrt{3}\cdot k^2e^2}{2m} \\ -2\omega\lambda & 0 & -\lambda^2 & 0 & 0 & 0 \\ 0 & -2\omega\lambda & \frac{m_1\omega^2}{m} & -\lambda^2 + \omega^2 & 0 & 0 \\ \frac{-3\sqrt{3}\cdot k^2e^2}{2m} & \frac{-3\sqrt{3}\cdot k^2e^2}{m_1} & 0 & 0 & -\lambda^2 - \frac{1}{4}\omega^2 & 0 \\ \frac{-3\sqrt{3}\cdot k^2e^2}{2m} & \frac{3\sqrt{3}\cdot k^2e^2}{2m} & 0 & 0 & \frac{-k^2e^2(4m_1-m)}{2m^2} & -\lambda^2 - \frac{9k^2e^2}{2m} \end{vmatrix} = 0.$$

The radical $\sqrt{3}$ can be removed by multiplying the last two columns by $\sqrt{3}$ and then dividing the last two rows by $\sqrt{3}$. Let

$$\omega^2 = k^2e^2u^2, \quad \lambda = Kex, \quad \text{then} \quad u^2 = 2(2m + m_1/mm_1.$$

After removing the factor K^2e^2, and reducing by the factor λ, which appears in the third row, and replacing the first column by the difference of the first and $2\omega/\lambda$ times the third we find

$$(8)\quad \begin{vmatrix} -x^2-\frac{7u^2}{4} & 0 & 2ux & 0 & -\frac{9}{2m} & -\frac{9}{m_1} \\ \frac{2m_1-5m}{2m^2} & -x^2+u^2+\frac{9}{2m} & 0 & 2ux, & -\frac{9}{2m} & \frac{9}{2m} \\ 0 & 0 & -x & 0 & 0 & 0 \\ \frac{-2m_1u^3}{mx} & -2ux & \frac{m_1u^2}{m} & -x^2+u^2 & 0 & 0 \\ -\frac{3}{2m} & -\frac{3}{m_1} & 0 & 0 & -x^2-\frac{u^2}{4} & 0 \\ -\frac{3}{2m} & \frac{3}{2m} & 0 & 0 & \frac{m-4m_1}{2m^2} & -x^2-\frac{9}{2m} \end{vmatrix} = 0.$$

Equation (8) shows another root $x=0$. Hence (7) has the double root 0.

Expanding (8) by the minors of the third row and multiplying and dividing by x we obtain the fifth order determinant

$$(9)\quad \begin{vmatrix} -x^2-\frac{7u^2}{4} & 0 & 0 & -\frac{9}{2m} & -\frac{9}{m_1} \\ \frac{2m_1-5m}{2m^2} & -x^2+u^2+\frac{9}{2m} & 2u & -\frac{9}{2m} & \frac{9}{2m} \\ \frac{-2m_1u^3}{m} & -2ux^2 & -x^2+u^2 & 0 & 0 \\ -\frac{3}{2m} & -\frac{3}{m_1} & 0 & -x^2-\frac{1}{4}u^2 & 0 \\ -\frac{3}{2m} & \frac{3}{2m} & 0 & \frac{m-4m_1}{2m^2} & -x^2-\frac{9}{2m} \end{vmatrix} = 0.$$

The mechanics of the situation leads us to suspect that equation (9) should have the root $x^2=-u^2$. Making this substitution, replacing the second row by the difference between the second and third rows and removing certain common factors the left member of (9) becomes

$$\begin{vmatrix} -\frac{3u^2}{4} & 0 & -\frac{9}{2m} & -\frac{9}{m_1} \\ \frac{11m+10m_1}{m} & 9 & -9 & 9 \\ -\frac{1}{2m} & -\frac{1}{m_1} & \frac{1}{4}u^2 & 0 \\ -\frac{3}{2m} & \frac{3}{2m} & \frac{m-4m_1}{2m^2} & u^2-\frac{9}{2m} \end{vmatrix}.$$

Replace the third column by the difference of the third and fourth.

Now multiplying the third column by $4/(m_1u)$ and subtracting from the fourth for a new fourth column it appears that the fourth and second columns are identical. Hence the determinant vanishes and equation (7) has the roots $\lambda = \pm i\omega$. We shall use this fact as a check on our expansion of (9) later. As a check on the correctness of the operations on equation (7) the author has substituted $\lambda = \pm i\omega$ in that determinant and found that it is satisfied.

We now expand (9) by the elements of the third column and each of the resulting fourth order determinants by the minors of the elements of the last column. This gives after some reductions

$$-\frac{36u^2}{m_1}\Delta_1 + 4u^2\left(x^2+\frac{9}{2m}\right)\Delta_2 + (x^2-u^2)\left(x^2+\frac{7u^2}{4}\right)\Delta_3 + \frac{27u^2}{4}(x^2-u^2)\Delta_4 = 0,$$

where

$$\Delta_1 = \begin{vmatrix} x^2+\frac{m_1u^2}{m} & x^2 & 0 \\ \frac{3u^2}{4} & \frac{3}{m_1} & x^2+\frac{1}{4}u^2 \\ 0 & \frac{3}{2m} & -x^2-\frac{m_1u^2}{m} \end{vmatrix}, \quad \Delta_2 = \begin{vmatrix} x^2+\frac{7u^2}{4} & 0 & \frac{9u^2}{4} \\ \frac{m_1u^2}{m} & x^2 & 0 \\ \frac{3}{2m} & \frac{3}{m_1} & x^2+\frac{u^2}{4} \end{vmatrix},$$

$$\Delta_3 = \begin{vmatrix} -x^2+u^2+\frac{9}{2m} & 0 & -\frac{9}{2m} \\ \frac{3}{m_1} & x^2+\frac{1}{4}u^2 & 0 \\ -\frac{3}{2m} & x^2+\frac{m_1u^2}{m} & x^2+\frac{9}{2m} \end{vmatrix},$$

$$\Delta_4 = \begin{vmatrix} -x^2 + \frac{m_1 u^4}{4} & -x^2 + u^2 + \frac{9}{2m} & +\frac{9}{2m} \\ \frac{1}{4}u^2 & \frac{1}{m_1} & 0 \\ 0 & \frac{3}{2m} & x^2 + \frac{9}{2m} \end{vmatrix} = 0.$$

Expanding these determinants and collecting according to powers of x we find the following equation of the 5th degree in x^2:

$$(10)\quad x^{10} + 4u^2x^8 + \left(\frac{87u^4}{16} + \frac{81u^2}{8m} - \frac{27}{2mm_1} - \frac{27}{m^2}\right)x^6 + \left(-\frac{31u^6}{8} + \frac{279u^4}{8m} + \frac{27u^4}{m_1} - \frac{81u^2}{4m^2}\right)x^4 + \left(\frac{7u^8}{16} + \frac{369u^6}{32m} + \frac{135u^4}{8mm_1} + \frac{459u^4}{16m^2}\right)x^2 + \frac{9u^8}{8m} + \frac{81u^6}{4m^2} = 0.$$

This equation should have the root $x^2 = -u^2$. Substituting and remembering that $u^2 = 2(2m+m_1)/mm_1$ it is fairly easy to verify that $x^2 = -u^2$ is a root of (10). Thus the degree of equation (10) can be reduced by dividing the left member by x^2+u^2. There results the following equation of the 4th degree.

$$(11)\quad x^8 + 3u^2x^6 + \left(\frac{15u^2}{m} + \frac{39u^2}{4m_1} - \frac{27}{2mm_1} - \frac{27}{m^2}\right)x^4 + \left(\frac{31u^4}{2m} + \frac{7u^4}{4m_1}\right)x^2 + \frac{9u^6}{4m} + \frac{81u^4}{4m^2} = 0.$$

If we choose the unit of mass so that $m=1$ and replace $1/m_1$ by y, u^2 becomes $2(2y+1)$ and equation (11) reduces to

$$(12)\quad x^8 + 6(2y+1)x^6 + 3(13y^2 + 22y + 1)x^4 + (2y+1)^2(7y+62)x^2 + 18(2y+1)^2(y+5) = 0.$$

For $y=0$ (12) becomes

$$(13)\qquad x^8 + 6x^6 + 3x^4 + 62x^2 + 90 = 0,$$

which factors readily into

$$(x^4 - 2x^2 + 10)(x^4 + 8x^2 + 9) = 0.$$

It follows that the roots of (12) for $y=0$ are

$$x^2 = 1 \pm 3\iota,\quad x^2 = -4 \pm \sqrt{7},\quad \iota = \sqrt{(-1)}$$

The Characteristic Exponents, $y \neq 0$. The parameter y is the ratio of the mass of one of the electrons to the mass of the nucleus. For our purposes it may be taken as .00014. We seek a solution of (12) in the form $x^2 = A + By \cdots$, the smallness of y making it unnecessary to go further than the first power. Direct substitution and equation to zero the coefficient of y gives

$$B = -\frac{3(4A^3 + 22A^2 + 85A + 126)}{2(2A^3 + 9A^2 + 3A + 31)}.$$

Hence

$$x^2 = 1 + 3\iota + \frac{-5 + 9\iota}{2}y, \quad x^2 = -4 + \sqrt{7} - \left(\frac{7}{2} - \frac{5}{7}\sqrt{7}\right)y,$$

$$x^2 = 1 - 3\iota + \frac{-5 - 9\iota}{2}y, \quad x^2 = -4 - \sqrt{7} - \left(\frac{7}{2} + \frac{5}{7}\sqrt{7}\right)y.$$

When y is given the numerical value above and the square root of the result is taken we find

$$x = \pm(\alpha + \beta\iota), \quad x = \pm\nu\iota,$$
$$x = \pm(\alpha - \beta\iota), \quad x = \pm\rho\iota,$$

where the numerical values of α, β, ν and ρ can be easily found.

It is clear from the above computations that the characteristic exponents for $y \neq 0$ differ very slightly from their values for $y = 0$.

The solutions of equations (7) are now all known. We group them together here for reference

$$\lambda = 0, 0, \pm\omega\iota, \pm Ke(\alpha + \iota\beta), \pm Ke(\alpha - \iota\beta), \pm Ke\nu\iota, \pm Ke\rho\iota.$$

The Solution of Equations (6). From the above values of the characteristic exponents we can write the general solutions of equations (6).

$$\begin{aligned}
x_i &= Ki_1 + Ki_2 t + Ki_3\epsilon^{+\omega\iota t} + Ki_4\epsilon^{-\omega\iota t} + Ki_5\epsilon^{Ke\nu\iota t} + Ki_6\epsilon^{-Ke\nu\iota t} + Ki_7\epsilon^{Ke\rho\iota t} \\
&\quad + Ki_8\epsilon^{-Ke\rho\iota t} + \epsilon^{Ke\alpha t}(Ki_9\epsilon^{Ke\beta\iota t} + Ki_{10}\epsilon^{-Ke\beta\iota t}) + \epsilon^{-Ke\alpha t}(Ki_{11}\epsilon^{Ke\beta\iota t} + Ki_{12}\epsilon^{-Ke\beta\iota t}). \\
y_i &= Li_1 + Li_2 t + Li_3\epsilon^{\omega\iota t} + Li_4\epsilon^{-\omega\iota t} + Li_5\epsilon^{Ke\nu\iota t} + Li_6\epsilon^{-Ke\nu\iota t} + Li_7\epsilon^{Ke\rho\iota t} \\
&\quad + Li_8\epsilon^{-Ke\rho\iota t} + \epsilon^{Ke\alpha t}(Li_9\epsilon^{Ke\beta\iota t} + Li_{10}\epsilon^{-Ke\beta\iota t}) + \epsilon^{-Ke\alpha t}(Li_{11}\epsilon^{Ke\beta\iota t} + Li_{12}\epsilon^{-Ke\beta\iota t}). \\
z_i &= Mi_1 + Mi_2 t + Mi_3\epsilon^{\omega\iota t} + Mi_4\epsilon^{-\omega\iota t} + Mi_5\epsilon^{Ke\nu\iota t} + Mi_6\epsilon^{-Ke\nu\iota t} + Mi_7\epsilon^{Ke\rho\iota t} \\
&\quad + Mi_8\epsilon^{-Ke\rho\iota t} + \epsilon^{Ke\alpha t}(Mi_9\epsilon^{Ke\beta\iota t} + Mi_{10}\epsilon^{-Ke\beta\iota t}) + \epsilon^{-Ke\alpha t}(Mi_{11}\epsilon^{Ke\beta\iota t} + Mi_{12}\epsilon^{-Ke\beta\iota t}).
\end{aligned} \tag{15}$$

where ϵ is the Naperian base and $i = 1, 3$.

All of the terms of these solutions are periodic except the linear term in t and those terms involving $\epsilon^{\pm Ke\alpha t}$. If the system is disturbed in any way it will, in general, break up because of the non-periodic terms. For general initial con-

ditions there will appear, in addition to the terms linear in t, oscillations of the following types:

1. Periodic, period $2\pi/\omega = 2\pi/(keu)$,
2. Periodic, period $2\pi/(kev)$,
3. Periodic, period $2\pi/(ke\rho)$,
4. Non-periodic damped vibrations arising from the terms $\epsilon^{-ke(\alpha \pm i\beta)t}$,
5. Non-periodic vibrations arising from the terms $\epsilon^{ke(\alpha \pm i\beta)t}$.

From the above results the following theorem is apparent:

In small oscillations of the neutral helium atom, near the equilateral triangle positions, the periods of the periodic terms are inversely proportional to the charge on each electron.

This theorem applies equally as well to the periodic portions of the non-periodic terms, excepting, of course, the linear terms in t.

There appear 72 arbitrary constants in the solutions (15). By well known methods we may choose twelve of them as the constants of integration and the remaining ones can be found as linear functions of the twelve. We choose L_{1j}, $j = 1 \cdots 12$ arbitrarily.

The determination of K_{12}, K_{32}, L_{32}, M_{12}, and M_{32} in terms of L_{12} is of particular interest. To effect this we substitute in equations (6):

$$x_i = Ki_1 + Ki_2 t, \quad y_i = Li_1 + Li_2 t, \quad z_i = Mi_1 + Mi_2 t, \quad i = 1, 3.$$

Since these must satisfy (6) identically in t, the coefficient of t and the constant terms must vanish. We find

$$K_{12} = K_{32} = M_{12} = M_{32} = 0, \quad L_{32} = (-m_1/2m)L_{12}.$$

Hence if the disturbance which produces the oscillations has no component away from the plane of the equilateral triangle L_{12} and L_{32} will be zero and there will be no linear term in t.

Let the initial condition be

$$x_i = a_i, \quad x_i' = b_i, \quad y_i = c_i, \quad y_i' = d_i, \quad z_i = b_i, \quad z_i' = g_i \text{ at } t = 0, \quad i = 1, 3.$$

Applying these conditions to equations (15) it is apparent that the twelve arbitrary constants L_{1j}, $j = 1 \cdots 12$ are linear functions of the initial constants. Therefore in order that each term of the solutions be periodic it is necessary to impose five linear conditions on the twelve initial constants. Seven of the twelve initial constants may be chosen arbitrarily and the other five may be determined uniquely by the conditions

$$L_{1,2} = 0, \quad L_{1,9} = 0, \quad L_{1,10} = 0, \quad L_{1,11} = 0, \quad L_{1,12} = 0.$$

If these conditions are satisfied each term of the solutions will be periodic with the periods

$$2\pi/\omega, \quad 2\pi/(kev), \quad 2\pi/(Ke\rho).$$

By imposing the three linear conditions on the initial constants, $L_{1,2}=0$, $L_{1,9}=0$, $L_{1,10}=0$ the solutions may be made to contain only periodic terms and damped vibrations. *Therefore nine of the initial constants may be chosen arbitrarily and the system consisting of the nucleus and two electrons will have only periodic oscillations or damped vibrations near the equilateral triangle positions.*

A NOTE PERTAINING TO KEPLER'S THIRD LAW

By D. H. RICHERT, Bethel College

The purpose of this note is to present in a simple way the derivation of Kepler's third law as corrected by Newton.

It is assumed that the orbit of a planet is circular so that the acceleration is along the normal.

Let M be the mass of the sun, m_1 the mass of a planet, T_1 its period and a_1 the mean distance between the centers of mass of sun and planet.

If a_1 is the radius of the circular orbit and T_1 the period, then the acceleration imparted by the sun to a unit mass of the planet is given by

$$GM/a_1^2, \tag{1}$$

where G is the constant of gravitation. Since this acceleration is along the normal it is equal to

$$(2\pi/T_1)^2 \cdot a_1, \quad \text{for} \quad v^2/a_1 = (2\pi a_1/T_1)^2(1/a_1). \tag{2}$$

Setting (1) equal to (2) gives

$$GM/a_1^2 = (2\pi/T_1)^2 \cdot a_1. \tag{3}$$

Similarly for a second planet of mass m_2, period T_2 and mean distance a_2 the relation

$$GM/a_2^2 = (2\pi/T_2)^2 \cdot a_2 \tag{4}$$

holds. From (3) and (4) follows Kepler's third law:

$$T_1^2 : T_2^2 = a_1^3 : a_2^3 . \tag{5}$$

A planet, however, describes its orbit not around the center of the sun but around the common center of gravity of sun and planet. If r_1 is the distance of the first planet from this common center of gravity, we must replace (2) by

$$(2\pi/T_1)^2 \cdot r_1. \tag{6}$$

Now $m_1 r_1 = M(a_1 - r_1)$, hence

$$r_1 = [M/(M + m_1)]a_1.$$

Using this value of r_1 (6) reduces to

$$(2\pi/T_1)^2[M/(M + m_1)]a_1. \tag{7}$$

Setting (1) equal to (7) gives

$$GM/a_1^2 = (2\pi/T_1)[M/(M + m_1)]a_1, \tag{8}$$

or

$$G(M + m_1)/a_1^3 = (2\pi/T_1)^2. \tag{9}$$

Similarly for the second planet the relation

$$G(M + m_2)/a_2^3 = (2\pi/T_2)^2. \tag{10}$$

From (9) and (10) follows

$$T_1^2(M + m_1) : T_2^2(M + m_2) = a_1^3 : a_2^3, \tag{11}$$

which is Kepler's third law as corrected by Newton.

QUESTIONS AND DISCUSSIONS

EDITED BY R. E. GILMAN, Brown University, Providence, Rhode Island

The department of Questions and Discussions in the Monthly is open to all forms of activity in collegiate mathematics, including the teaching of mathematics, except for specific problems, especially new problems, which are reserved for the department of Problems and Solutions.

A MNEMONIC FOR EULER'S CONSTANT

By MORGAN WARD, California Institute of Technology

The first ten digits for Euler's constant may be remembered by aid of the following mnemonic:

"These numbers proceed to a limit Euler's subtle mind discerned."

5 7 7 2 1 5 6 6 4 9

Since the next significant figure is a zero, the sentence comes to a very natural stopping place.

RECENT PUBLICATIONS

EDITED BY ROGER A. JOHNSON, Brooklyn College of the City of New York

All books for review should be sent directly to the editor of this department, at Brooklyn College, 66 Court Street, Brooklyn, N. Y., and not to any of the other editors or officers of the Association.

NEW BOOKS RECEIVED

Contributions to the Calculus of Variations. The University of Chicago Press, 1930. Lithoprinted. 350 pages, $3.00.

A collection of five dissertations in the field of Calculus of Variations, reproduced directly from type-written copy.

Fourier'sche Reihen, mit Aufgaben. Von J. Wolff, Utrecht. Groningen, P. Noordhoff N.V., 1931. 60 pages.

Vorlesungen über einige Klassen nichtlinearer Integralgleichungen und Integrodifferentialgleichungen. Von Leon Lichtenstein, Leipzig. Berlin, Julius Springer, 1931. x+164 pages. RM 16.80.

Analytical Mechanics, for Students of Physics and Engineering. By H. M. Dadourian. Third Edition, Revised. New York, D. Van Nostrand Company, 1931. xiv+428 pages. $4.00.

Fundamentals of Electricity and Magnetism. By Leonard B. Loeb. New York, John Wiley & Sons, 1931. xx+432 pages. $4.00.

Craftsmanship in the Teaching of Elementary Mathematics. By F. W. Westaway. London, Blackie and Son, 1931. xvi+666 pages.

Intermediate Calculus. By Percey F. Smith and William R. Longley. New York, Ginn and Company, 1931. xiv+458 pages.

Applications of the Absolute Differential Calculus. By A. J. McConnell. London, Blackie and Son, 1931. xii+318 pages. 20 s.

Geschichte der Elementar-Mathematik. Von J. Tropfke. Erster Band, Rechnen. Dritte, verbesserte, und vermehrte Auflage. Berlin, Walter de Gruyter & Co., 1930. x+224 pages.

Algebraische Theorie der Körper. Von Ernst Steinitz. Neu herausgegebenen, mit Erlauterungen und einem Anhang: Abriss der Galoisschen Theorie versehen, von R. Baer und Helmut Hasse. Berlin, Walter de Gruyter & Co., 1930. 150 pages.

Thermodynamics. By A. W. Porter. New York, E. P. Dutton, 1931. viii+96 pages. $1.10.

Einführung in die Theorie der Kontinuierliche Gruppen. By G. Kowalewksi. Leipzig, Akd. Verl. M.B.H., 1931. x+396 pages.

Strahlenoptik. By M. Herzberger. Berlin, Julius Springer, 1931. xiv+196 pages. Paper, 18 marks.

The Cultural Significance of Accounts. By D. R. Scott. New York, Henry Holt and Company, 1931. x+316 pages.

Relativitätstheorie als Verstandliche Wissenschaft. By L. Hopf. Berlin, Julius Springer, 1931. viii+148 pages.

REVIEWS

Differentialgleichungen Reeller Funktionen. By E. Kamke. Mathematik und ihre Anwendungen in Monographien und Lehrbüchern. Band VII. Akademische Verlags-Gesellschaft m.b.H., Leipzig, 1930, xiv+436 pages, with 43 figures.

The outstanding feature of this excellent text on differential equations in the real domain is the exhaustive treatment of existence theorems for the ordinary

case. Methods of solution are developed in ample manner but more stress is laid on the properties of the solutions.

For the second order linear system the polar coordinate form is used to develop the usual oscillation and other properties associated with the work of Sturm. In this method, the central idea is to make use of the angle function and to exhibit directly the two solutions of the system as sine and cosine of this angle. This device was first published by Prüfer in 1926 in the "Mathematische Zeitschrift."

The treatment of partial differential equations is confined to equations of the first and second order. A brief discussion of the vibrating string is found in the last section.

At the close of the book are found the solutions of the forty-four splendid problems scattered throughout the text. More such problems would be desirable. Finally references are given to articles in the Encyclopädie der Mathematischen Wissenschaften and a list of text books is included.

H. J. ETTLINGER

The Principles of Quantum Mechanics. By P. A. B. Dirac. The International Series of Monographs on Physics. Oxford University Press, Oxford, 1930. x+257 pages. $6.00.

Dirac's contributions to the development of quantum mechanics have been of great importance. The method used in this book is to postulate two kinds of numbers; the first kind are *complex* and the second kind are vectors representing states. Laws of operation are assumed and this elementary skeleton is gradually clothed with more and more flesh until it pulses with the life blood of modern quantum mechanics.

As the hand of the author proceeds to erect the mathematical framework, addition, multiplication, conjugates, functions, expansion theorems, *Eigenvalues*, probability, differentials, contact transformations, Poisson brackets, matrices make their successive appearance. From these abstract beginnings emerge the foundations stones of quantum mechanics, the physical stuff such as electrons, protons, photons, radiation, polarization, emission, absorption, Schroedinger's wave equation, de Broglie's group velocities, Heisenberg's matrices, electron spin, Zeeman effect, Heisenberg's principle of indeterminacy, Einstein's law of radiation not in historical order but in convincing form.

Dirac's present book is a very valuable and clear contribution, in a field where mathematical complexities threatened to overwhelm the average interested scientist.

H. J. ETTLINGER

Advanced Calculus. By George A. Gibson. MacMillan and Company, London, 1931. xviii+510 pages. $6.50.

Someone has said that a course in advanced calculus can be most anything. We grant this provided the "most anything" includes: (1) a careful discussion

of the ideas of continuity, derivative, and differential, as applied to a function of a single variable, with examples of the various types of discontinuous functions; (2) a rigorous study of infinite sequences and series with special emphasis on the concepts of uniform and non-uniform convergence; (3) a study of partial derivatives, and differentials of a function of more than one variable, with an extensive drill in the formal processes involved in partial differentiation, change of variable, and the various applications of these to line, surface, and space integrals; (4) the existence theorems for implicit functions; (5) a thorough, but not too extended, treatment of integration based on Riemann's definition.

How does the book under review "measure up" on these points? In regard to the first, the ground is well covered, and the illustrations are happily chosen. It is, perhaps, desirable to have a few more examples of the various types of discontinuities. The notation $f'(x)$ is used to designate the derivative. The symbol dy/dx is not introduced until the differential is defined, which is as it should be. The geometric interpretation of the differential is omitted.

On the question of series and sequences, the author begins pretty much *in medias res*. It is taken for granted that the reader is thoroughly familiar with the concepts of convergence and divergence, and with the simpler tests for each. This is certainly not true of the rank and file of students on this continent who enter advanced calculus classes. Some previous contact with the ideas of uniform and non-uniform convergence also seem to be assumed. The significance of uniform convergence is stated clearly enough, and some examples are given of series which converge uniformly. On the other hand, not a single example comes to our notice which illustrates what uniform convergence is not. This is a defect. It would almost appear that the author had read neither Osgood's classical paper in the American Journal of Mathematics, vol. 19, nor his discussion of sequences and series in his *Funktionentheorie*. We greatly fear that he who gets his first orientation to the idea of uniform convergence from Professor Gibson's book will be in a position with the student who said to his teacher: "You have told me three times what uniform convergence is, and now I don't know it again."

Among the other topics coming under the head of series are: substitution of a series in a series; Abel's theorem; revision of series; the rearrangement of terms of a series; the more delicate convergence tests of Kummer, Gauss, Raabe, Abel, and Dirichlet. These are discussed in a very satisfactory manner. There is also a study of the remainder in Taylor's theorem, which is based on algebraic forms. While the treatment is excellent, it is not, perhaps, the best method of approach for the student who is taking up this topic for the first time.

The treatment of partial derivatives and of total differentials is adequate and concise. It is followed by the usual discussion of change of variables, in which a few general problems are dealt with. It usually happens that the student who first assimilates the methods of these general problems is liable to try to apply the formulas there developed to each particular situation that arises. This can be avoided by going from a careful study of partial and total

derivatives directly to exercise involving change of variable. The student will, for the most part, got his results by devious and clumsy methods. He will, however, acquire power and confidence in performing this type of work, which, after all, is the important thing. Professor Gibson's book lends itself admirably to such a procedure for the reason that the list of exercises is copious and varied.

The chapter on implicit functions follows the usual lines. The conditions under which the various theorems are proved are more drastic than is necessary, but this is an advantage if the book is to be used in introductory courses. Another commendable feature is the careful and enlightening way in which the reader is shown just what the theorems are all about.

In his presentation of the theory of integration the author has adhered to the definition of Riemann, and has accomplished the utmost possible without recourse to the modern point set theory. Several of the principal theorems are stated in more than one way. The technique is distinctive and pleasing, and the emphasis, for the most part, properly placed. Especially to be commended is the discussion of the change of order of integration for improper double integrals. In all seven chapters are devoted to the various phases of integration. One is surprised to find that no mention is made of the usual theorems on integration of series and sequences.

In these days the working tool of the mathematician is the modern theory of integration based on measurable sets and measurable functions. All the theorems concerning Riemann integrals are special cases of theorems in the modern theory and, for the most part, more elegantly obtained by means of the modern theory. This being the case, one wonders if Professor Gibson is justified in devoting so much space to Riemann integrals.

Other topics are: A good introductory exposition of the real number system; a chapter on sets, sequences, and limiting points, which includes the Bolzano-Weierstrass theorem and Cauchy's necessary and sufficient conditions for the existence of a limit; derivatives of determinants; Wronskians; linear dependence of functions; complex functions of a real variable. In connection with the latter we find the remark: "It is fairly evident that

$$\left| \int_a^b w dx \right| \leqq \int_a^b |w| \, dx," \quad w = u + iv."$$

Possibly it is evident for Riemann integrals, but I think the reader will agree that it needs proof in the case of Lebesgue integration.

There is also included a brief but good discussion of the Gamma function, both as the limit of a product and as an integral, and a chapter on infinite products. The treatment of infinite products assumes no previous knowledge on the part of the reader. The definitions and first principles are clearly and effectively stated. Of such theorems as are given, the proofs are concise but contain sufficient detail to make easy reading for the novice.

It is our opinion that Professor Gibson's book is a valuable contribution to the literature in the field which it covers. Only the occasional teacher will find

it suitable for class room use, but it should be a part of the working equipment of every student and instructor of advanced calculus.

R. L. JEFFERY

Geometry of Four Dimensions. By A. R. Forsyth, Cambridge University Press, 1930, vol. 1, xxix+468 pages, vol. 2, xi+520 pages.

This compendious two volume work (about 1000 pages) deals with its subject matter in an avowedly old-fashioned spirit: no tensors, little abridged notation; for instance, the coordinates are denoted by x, y, z, v rather than x_1, x_2, x_3, x_4. The presentation makes a point of explicitness and everything is written out *in extenso*. Forsyth, with his encyclopedic outlook, does this sort of thing very well, and has here performed a valuable service by taking the trouble to carry out to the end and exhibit in full detail what most geometers would be content to indicate in principle, seeming to follow Schopenhauer's dictum that everything that can be done should be done so that the history of the world may be complete.

The work divides itself into five parts:

1°. Linear sub-manifolds, one, two, three-dimensional; the fundamental four-space is itself assumed linear (flat, homaloidal).

2°. Skew curves in the four-space; there is also a section on skew curves in n-space.

3°. Surfaces as existing freely in the four-space, without reference to three-dimensional manifolds in which they may be contained.

4°. Regions, i.e., three-dimensional sub-manifolds of the four space.

5°. Invariants under rigid motion and under arbitrary change of parameters of curves, surfaces and regions, as embedded in one another and existing freely in the four-space.

The following samples of terminology may be of use to the prospective reader. *Homaloid*, a general term including: *line*, one-dimensional linear manifold; *plane*, two-dimensional linear manifold; *flat*, three-dimensional linear manifold; and the fundamental four-space. *Orbiculate amplitude*, a comprehensive term including: *circle*: $x^2+y^2=a^2$, $z=0$, $v=0$; *sphere*: $x^2+y^2+z^2=a^2$, $v=0$; *globe*: $x^2+y^2+z^2+v^2=a^2$.

The *principal directions* of a curve are its *tangent*, *principal normal*, *binormal* and *trinormal*: the last is perpendicular to the *osculating flat*, having four consecutive points in common with the curve. A curve has *curvature* $1/\rho$, *torsion* $1/\sigma$, and *tilt* $1/\tau$, this being dw/ds where dw, the *angle of tilt*, is the angle between two consecutive osculating flats. The Frenet formulas with their skew-symmetric matrix of coefficients $1/\rho$, $1/\sigma$, $1/\tau$, are set up. There is an osculating circle, sphere, and globe to the curve, each with its center and radius.

Surface means a two-dimensional manifold, *region* a three-dimensional manifold contained in the basic four-space. The geodesics of a surface are studied,

its lines of curvature, and other properties expressing its relation to the surrounding four-space.

In the theory of regions are included geodesics and minimal surfaces relative to a given region; the latter are surfaces of least area among those lying entirely in the region and bounded by a prescribed closed curve of the region. Quadric regions, defined by an equation of the second degree in the four coordinates, are studied. The general theory of surfaces as contained in a region is taken up; in particular, the geodesics of the surface are studied in their relation to the region in which the surface is embedded. The *globular representation* of a region generalizes the classic Gauss spherical representation. A region has three principal centers of curvature, whose locus is the *centro-region* (evolute). *Nul-surfaces*, of identically vanishing area, in a given region are discussed. Minimal regions are considered; these are regions of least volume with a given two-dimensional boundary.

The work ends with the theory of invariants of geometric configurations in the four-space. The fundamental group is the metric group of the coordinates combined with the total group of parameter transformations. The Lie theory is used, and a large number of invariants are set up explicitly, wherein only algebraic and differential operations are used supplemented by the integration of linear partial differential equations. Geometric interpretation is found for many of the invariants.

The reader who wishes to see, in concrete and explicit form, the actual features of four-dimensional geometry will find his wish amply met by browsing through Forsyth's book.

J. DOUGLAS

Elementare Reihenlehre. By Hans Falckenberg. Sammlung Göschen, Walter de Gruyter, 1926, 136 pages.

Komplexe Reihen. Nebst Aufgaben über reelle und komplexe Reihen. By Hans Falckenberg. Sammlung Göschen, Walter de Gruyter, 1931, 140 pages.

The first little book contains a brief treatment of the real number system and a conventional treatment of the simpler features of the classical theory of sequences and series of real variables. The pages on the elementary functions as defined by series are one of its best parts.

The second book is supplementary to the first. There are twenty-four pages treating series in the complex domain. The remainder of the volume is given to exercises and their solutions. There are many excellent and natural exercises to accompany a course on series. However, in my opinion the name *exercise* is belied when there is an accompanying solution; and inasmuch as the accumulation of sets of exercises without solutions readily available is a valuable addition to the literature of those subjects taught in our universities, I feel that this volume is not as helpful as it should be to the cause of university teaching.

TOMLINSON FORT

Funktionentheorie, Erste Teil: Grundlagen der allgemeinen Theorie der analytische Funktionen. Vierte, verbesserte Auflage. By Konrad Knopp. Sammlung Göschen, Walter de Gruyter, 1930.

There is little doubt but that this is the best monograph on functions of a complex variable yet written. The author has compressed an astonishing amount within its one hundred and thirty eight small pages and all is written with the utmost clarity and in a most interesting style. The present edition differs in detail only from earlier editions with which most teachers of the subject are already familiar and to such it needs no recommendation. To those unfamiliar with any edition the following chapter headings will give some idea of the scope of the present little book: I: "Punktmengen in der Ebene;" II: "Funktionen einer komplexen Veränderlichen;" III: "Das Integral einer stetigen Funktionen;" IV: "Der Cauchysche Integralsatz;" V: "Die Cauchyschen Integralformeln;" VI: "Reihen mit veränderlichen Gliedern;" VII: "Die Entwicklung analytische Funktionen in Potenzreihen;" VIII: "Analytische Fortsetzung und vollständige Definition der analytischen Funktionen;" IX: "Ganze transzendente Funktionen;" X: "Die Laurentsche Entwicklung;" XI: "Die verschiedenen Arten singulärer Stellen."

The monograph in question should be studied in conjunction with the second volume by the same author: *Anwendungen und Weiterfuhrung der allgemeinen Theorie.* The scope of this is partly indicated by the following chapter headings from the 1920 edition: I: "Ganze Funktionen;" II: "Merimorphe Funktionen;" III: "Periodische Funktionen;" IV: "Wurzel und Logarithmus;" V: "Algebraische Funktionen;" VI: "Das analytische Gebilde."

Accompanying each volume is a volume of exercises by Professor Knopp and also of the Sammlung Göschen. These should be in the hands of every teacher of the theory of functions of a complex variable.

TOMLINSON FORT

Niels Henrik Abel. Eine Schilderung Seines Lebens und Seiner Arbeit. By Dr. V. Bjerknes. Julius Springer, Berlin, 1930. v+136 pages.

Two years ago the world commemorated the centenary of the death of Niels Henrik Abel on April 6, 1829. This brought forth a number of books and brochures dealing with his distinguished services to mathematics and his absorbingly interesting life history. Of these many biographies and reviews probably none surpasses that of Dr. Bjerknes for keen understanding of the mathematician and man Abel, and for a lucid setting forth of the inner events of his life. It is a complement to the mathematical memoirs on Abel written by his father, C. A. Bjerknes, in 1880. Written in Norwegian in 1929, it has now been translated into German.

Abel's life reminds one of a Shakespearian tragedy, even to the swift-moving climax. From childhood on, it was the struggle of a man's mind and soul and body against the exigencies of life in a world which knows not always genius.

It was a pitifully uneven struggle for shelter and mere physical sustenance by one all afire with a consuming zeal for mathematical discovery; and an even greater struggle to get the mathematicians of his day to understand and appreciate his discoveries. Except from Holmboe and Crelle, he met only apathy and non-understanding. The cold reception of Gauss, Cauchy, and Legendre was gall to his fine, sensitive, often shrinking nature. By the efforts of Holmboe he received a stipend from the state to study abroad two years (1825–1827). In October, 1826 he submitted his now well-known memoir on transcendental functions to the French Academy. In this memoir was included his famous addition theorem. With inexcusable negligence the committee, Cauchy and Legendre, put it aside. On the results of this memoir young Abel had staked his hopes for a professorial appointment to the university at Christiania or for a renewal of his stipend. Now he received neither. Deeply in debt he had to discontinue his studies abroad. The next year, 1828, he eked out existence as a substitute lecturer in a military high school and also gave one course at the university.

Finally, even for him, better days seemed coming. His contributions in Crelle's Journal began to create attention, and through the influence of Crelle an appointment to the University of Berlin was forthcoming. In December, 1828 he made a trip to spend Christmas with his fiancee. It was a strenuous trip; and it is said that his clothing was insufficient. He caught a cold that later settled on his lungs. His body, weakened by want, was not equal to the emergency, and he died on April 6, 1829, at the early age of 27.

On his death bed, knowing his days were to be few, he re-wrote for Crelle's Journal the main points of the addition theorem that had been submitted to and pigeon-holed by the Paris committee. As he lay there looking at the two closely-written pages of the proof of his immortal theorem, which in a short period of convalescence he had salvaged for the world, he concluded optimistically: "I shall later bring out numerous applications of this theorem which will throw light on the functions in question." Says Mittag-Leffler: "January 6, 1829 is more worthy to be remembered in the history of civilization than the memorial days of kings, emperors, and countries. On this day Abel, lying in bed, wrote the greatest thought of his life for Crelle's Journal, the Abelian addition theorem, which was hailed forthwith as "monumentum aere perennius," and which even now, 100 years after Abel's birth, is looked upon as the high-point of the development of mathematics."

The irony of life! Two days after his death came the announcement of his appointment to the Berlin professorship. And a few months later Legendre read through the memoir on transcendental functions submitted three years before, and there was found the addition theorem. Both Cauchy and Legendre gave it unstinted praise. But the 24-year old author, who desperately needed that recognition in 1826, was no more.

Bjerknes gives considerable space to Abel's correspondence. Abel was a very fine letter writer, and narrates and comments with all the zest and spontaneity

of a young man on his first travels, to whom many things in life are new. We must remember that Abel never reached his 27th birthday. In these letters we learn that he seldom came to a city without visiting one or two theatres. That one luxury he allowed himself, even if the meals had to be slim. Often he was homesick, desperately homesick. His impression of Paris undoubtedly reflects the reception he had met there. "All want to instruct," he says, "no one wishes to learn. The only things a Frenchman desires from foreigners are things of practical import; as to thinking, he believes that can only be done by them."

Bjerknes has aimed to make real for us not only the scholar Abel, but the youth and the young man Niels Henrik,—his friendships, his love romance, his travels, his plans, his hopes. In this he has succeeded admirably. The reviewer has no adverse criticism of sufficient import to mention in a formal review. He only regrets that there is not an English translation for the many readers who do not read German.

M. A. NORDGAARD

MATHEMATICS CLUBS

EDITED BY F. M. WEIDA, The George Washington University, Washington, D. C.

All reports of club activities should be sent to F. M. Weida, The George Washington University, Washington, D. C. All manuscript should be typewritten, with double spacing, and with margins at least one inch wide.

CLUB ACTIVITIES

LOCAL MATHEMATICS CLUBS

Rutgers University Mathematics Club.

The officers for the year 1930–1931 were: Richard M. Creamer, President; E. E. Rutgers, Vice President; Isadore Chertoff, Secretary-Treasurer; C. L. Hickok, Chairman, Membership Committee.

These officers were elected by the club in May, 1930.

The aim of the club is to promote interest and scholarship in the field of mathematics and to point out the progress of the science. The membership of the club is composed of 18 students and the teaching staff, of which there are ten.

The meetings and programs were as follows:

October 1930: "Fractions among the Egyptians and Babylonians" by A. E. Smith; "Continued fractions" by R. M. Creamer; "Combinations and the binomial theorem" by Professor E. P. Starke.

November 1930: "Coordinate systems" by Professor S. E. Brasefield.

December 1930: "Archimedes and his relation to calculus" by Richard Coan; "Curve fitting" by Instructor C. R. Wilson; "The theory of magic squares" by J. Chernick.

January 1931: "Analytical treatment of some properties of the orthopole" by Professor R. Morris; "Morley's theorem on the triangle" by L. Schulman and N. Schwartz; "Formulas for the sides of a triangle in terms of the altitudes" by I. Chertoff.

February 1931: "Fourier series" by Instructor Jacob Goodman; "Inscribing a rectangle within a rectangle" by E. B. Crane; "Hyperbolic functions" by D. K. Roberts.

March 1931: "Ideal points and lines" by Instructor H. B. Huntley; "The notion of number" by C. L. Hickok; "Mathematics as a branch of logic" by L. C. Vass.

April 1931: "Elliptic integrals" by E. E. Rutgers; "A unique integration" by C. L. Hickok; "Calculus of finite differences" by M. Freedman; "The transcendental numbers π and e" by I. Kaufman; "Curves having no derivatives" by W. H. Glover.

May 1931: "An account of Dr. Michelson's life and work" by Professor A. L. Greenlees; "The atom" by J. J. Jelicks and G. A. Downsbrough; "A problem in probabilities" by I. J. Millner.

The club in cooperation with the club at the New Jersey College for Women, sponsored two lectures by visiting speakers during the year, namely, Professor R. C. Archibald of Brown University spoke on "Mathematics prior to the Greeks" and Dr. S. A. Schelkunoff of the Bell Telephone Laboratories spoke on "Telephony and the application of mathematics to some of its problems."

The year's meetings closed with the annual banquet.

ISADORE CHERTOFF, *Secretary.*

Case Mathematical Club, Case School of Applied Science.

The Case mathematics club was organized for the purpose of stimulating the study of mathematics, for the purpose of giving the students an appreciation of the unity of the field of mathematics, and for the purpose of showing to the students the beauty of non-technical and modern mathematics in a way which is impossible in the class room.

Any undergraduate or post-graduate student and any member of the faculty is eligible for membership in the club. The sole requirement is that he be interested in mathematics and attend the meetings of the club regularly. Nominal dues of $1.00 per term are required of regular members.

The officers for 1930–1931 were: Louis G. Henyey, President; John R. Parks, Vice President; Chester J. Stoemple, Secretary and Treasurer; Briggs H. Napier, Recording Secretary.

The active members during the past year numbered about 30.

The meetings and programs were as follows:

May 16, 1930: "Geometries of higher space" by Dr. Max Morris, Assistant Professor of mathematics.

October 10, 1930: "Sets of integers with equal sums of like powers" by Dr. O. E. Brown, Instructor in mathematics.

October 23, 1930: "Theorems in modern geometry" by Dr. J. R. Musselman, Professor of mathematics at Western Reserve University.

November 7, 1930: "Homogeneous coordinates and the line at infinity" by Mr. B. C. Getchell, Instructor in mathematics.

November 21, 1930: "Approximations to the value of Pi" by J. R. Parks.

December 19, 1930: "The calculus of finite differences" by C. Shepherd.

January 9, 1931: "Theory of groups and transformations" by Louis G. Henyey.

February 20, 1931: "The algebra of matrices and quaternions" by Mr. G. N. Garrison, Instructor in mathematics.

March 13, 1931: "Irrational numbers" by Mr. R. S. Burington, Instructor in mathematics.

March 27, 1931: "The mathematical solution of Cryptograms" by James Black.

April 17, 1931: "A method for determining the orbits of binary stars" by Dr. J. J. Nassau, Professor of Astronomy.

May 1, 1931: "A problem in Astronomy" by Assistant Professor E. M. Justin.

May 14, 1931: "The unity of mathematics" by Professor W. G. Simon, Western Reserve University.

The meetings are generally held at the school, but this year several were held off the campus. The meeting of May 6, 1930 was held at the home of President Wickenden; the meeting of October 23, 1930 was held in the home of Dean Focke. A meeting at the Case Astronomical Observatory was held on November 7, 1930. The final meeting of the year, a dinner meeting, was held at the Case Social Club on May 14, 1931.

BRIGGS H. NAPIER, *Secretary.*

Mathematics Club of the University of California at Los Angeles.

The aim of our mathematics club is the advancing of mathematics, the promoting of good fellowship among those interested in mathematics and the upholding of the traditions of the

University. Membership is open to all members of the faculty of the department of mathematics. Student membership is open to the students who have taken or are taking calculus. Secondary membership is open to any other student interested in mathematics. All members are entitled to vote but only primary members may hold office. Officers are elected for a period of one semester. They assume their duties at the beginning of the semester following their election.

The number of active members this year was thirty. The average attendance at the meetings, including faculty members, was about twenty.

The officers for the first semester were: Reed Lawlor, President; Alta Blackford, Vice President; Nadga Gray, Secretary; Lyle Sullivan, Treasurer; Virginia Woods, Librarian.

The officers for the second semester were Reed Lawlor, President; Alta Blackford, Vice President; Jean Robb, Secretary; Inez Hopkins, Treasurer; Norman Hinton, Librarian.

The meetings and programs were as follows:

September 24, 1930: "Horner's method" by Reed Lawlor.

November 5, 1930: "Method of determining the area of polygons" by Ernest von Seggern.

December 10, 1930: "The ideas of the calculus in every-day life" by Dr. Hedrick; "Glimpses into the lives of great mathematicians" by Miss H. Glazier; "The number of rational roots satisfying the equation" by Mr. John Hill; "Requisites for a good student are those needed in every-day life" by Dr. James.

January 14, 1931: "Measurement of stellar distances" by Melville Short.

February 18, 1931: "The relation between mathematics and philosophy" by Norman Hinton.

March 18, 1931: "Mathematical fallacies" by Dr. Raymond Garver; "Mathematical puzzles" by Miss Evelyn Fink.

April 22, 1931: "The honey-bee and the calculus" by Miss Evelyn Fink.

May 20, 1931. "Farewell address by the President." Election of officers for 1931–1932.

In November twenty members and friends hiked to Robert's Camp and spent Saturday and Sunday there. Lunch, dancing and bridge were featured.

On December 27, a bridge party was held in Newman Hall. There were about 100 people present including Professors and alumni.

On March 12, twenty members and their guests went to the Clark observatory. After visiting the observatory, a reception was held at the home of the Vice President, Alta Blackford.

On May 8, the club enjoyed a swimming party at the Deauville Beach Club. About fifteen were present.

JEAN ROBB, *Secretary.*

Mathematics Club of the Harris Teachers College.

The report covers the activities from September 1930 to January 1931. The sponsor of our club is Dr. Jesse Osborn, Professor of mathematics. The meetings are held biweekly.

The officers for the term were. Esther Berger, President; Dorothy Bahn, Vice President; Hildegard Graefe, Secretary-Treasurer; Mary Messina and Jennie Louise Waddell, representatives to college publication.

The meetings and programs were as follows:

October 6, 1930: "Astronomy" by Beth Murry; "Comets and meteors" by Bernice Rahn.

October 20, 1930: "Ancient number systems" by Elizabeth Lisy; "Men important in the history of mathematics" by Dorothy Bahn.

November 3, 1930: "Mathematics as amusement" by Iola Uhrhans; "Magic squares" by Hazel Willisan.

November 17, 1930: "The continents and oases of Mars" by Margaret Ellsperman; "Astronomy" by Anastasia Snabada.

December 1, 1930: "History of problems" by Dorothy Close; "The development of geometry" by Dorothy Bennet.

December 15, 1930: "Astronomy" by Mr. Miller, Professor of Chemistry.

January 5, 1931: "Puzzles and simple problems" by Eleanor Erskine and Candace Wesbrock.

HILDEGARDE GRAEFE, *Secretary.*

The Mathematics Club of the Cooper Union Institute of Technology.

The officers for 1930–1931 were: L. A. Kenworthy, '31, President; J. J. Murphy, '31, Vice President; J. W. Kinkel, '33, Secretary; C. H. Kropp, '33, Treasurer; E. H. Ryan, '33, Assistant Secretary.

The club has a membership of 163.

The meetings and programs were as follows:

November 6, 1930: "Transformations" by Mr. F. H. Miller, Columbia University.
December 4, 1930: "Elliptic and hyperbolic functions" by G. Kosolopoff, '32.
December 18, 1930: "Theory of the slide-rule and its uses" by G. O'Sullivan, '31.
January 28, 1931: "Harmonic ratio" by L. D. N. Green, '34.
February 26, 1931: "Algebraic charts" by W. W. Rigrod, '33.
March 19, 1931: "Trisection of an angle" by K. Itkin, '34.
April 9, 1931: "Mathematical work of the Bureau of Standards" by Mr. Irving Hartmann.
April 16, 1931: "Vector analysis" by Professor W. J. Pickett.
Election of officers.

C. H. LEHMANN, *Faculty Advisor.*

Dartmouth Mathematical Club, Dartmouth College

The Dartmouth Mathematical Club was founded on October 6, 1930 "to make possible the presentation and discussion of subjects of general mathematical interest." Although primarily an undergraduate club, membership is open to anyone interested on payment of the regular dues of one dollar per semester. There are at present twenty-two members, and frequently non-members are guests at the meetings.

Meetings are ordinarily held every two weeks while College is in session. It is customary to serve refreshments during the discussion following each meeting.

The officers for 1930–1931 were: Earle L. Morawski, '31, President; Emerson Cooley, '31, Vice President; Merit P. White, '30, Secretary-Treasurer.

The meetings and programs were as follows:

October 6, 1930: "Ovals and equiangular polygons" by Professor J. W. Young.
October 20, 1930: "Poincaré's world" by E. L. Morawski, '31.
November 3, 1930: "World maps" by Professor B. H. Brown.
November 17, 1930: "Russell's mathematical logic" by R. B. Colburn, '33; "Mathematical paradoxes" by H. Howe, '33.
January 5, 1931: "Magic squares" by E. T. Mecutchen, '31.
January 19, 1931: "The Mosaic law" by Professor C. E. Wilder.
February 11, 1931: "Mathematical curiosities" by E. Cooley, '31; E. T. Mecutchen, '31; E. L. Morawski, '31; Readings from Leacock's "Literary Lapses" by Dr. R. Robinson.
March 23, 1931: "Mathematical tricks" by E. C. Corson, '34; "Solution of the cubic equation" by Frank Engel, '34; "Solution of the quartic equation" by George Engel, '34.
April 13, 1931: "The nine-point circle" by Dr. F. W. Perkins.
April 27, 1931: "History of mathematical notation" by W. C. Johnson, '33; "History of the slide rule" by Edwin B. Thomas, '34.
May 18, 1931: "Special relativity" by E. L. Morawski, '31; Election of officers for 1931–1932.

ROBIN ROBINSON, *Chairman Departmental Committee Advisory to the Mathematical Club.*

The Mathematics Club of the University of Kansas

The officers for 1930–1931 were: Lilly Somers, President; Margaret Sturges, Vice President; Elizabeth Hyer, Secretary-Treasurer. The officers are elected the spring of the preceding year by a committee and elected at a general meeting. There are thirty-eight active members and fourteen faculty members. The purpose of the club is to stimulate interest in mathematics and to discuss

interesting topics which do not arise in the classroom. The members are selected by the faculty from the outstanding students who have ten or more hours of credit in mathematics.

The meetings and programs were as follows:
October 20, 1930: Business meeting.
November 3, 1930: "Peculiar properties of circulates" by Mr. Philip Bell.
November 17, 1930: "Determinants" by Professor E. B. Stouffer.
December 1, 1930: "Einstein's film."
December 15, 1930: "Electrical integrators and harmonic analyzers" by Mr. Billy Moore.
January 12, 1931: "Geometric method for solving a biquadratic equation" by Miss Winona Venard.
February 16, 1931: "Pi and how to get it" by Mr. Howard Wingert.
March 2, 1931: "Multiple correlation and how to predict it" by Professor Dinsmore Alter.
March 16, 1931: "The Pascal triangle" by Miss Carol Stratton.
March 30, 1931: "Reversing digits" by Professor Guy Smith.
April 13, 1931: "Simple Harmonic Motion" by Professor J. J. Quinn, St. Mary's College.
April 27, 1931: Business meeting.
May 14, 1931: Picnic.

ELIZABETH HYER, *Secretary.*

Students Mathematical Round Table of the University of Illinois.

The officers for 1930–1931 were: First Semester—C. A. Jackokes, President; Ella Marie Meythaler, Secretary; R. H. Skidmore, Treasurer. Second Semester—Wm. Ted Martin, President; Anice Seybold, Secretary; Gertrude Stith, Treasurer.

The object of the club is to interest students of mathematics in various phases of the subject not usually included in the standard mathematical courses, to stimulate the reading of current mathematical literature, and to keep its members informed in as non-technical a fashion as possible concerning the progress of mathematics and mathematical education. The members consist of graduate students and upper classmen interested in mathematics.

The meetings and programs were as follows:
October 30, 1930: "Polar reciprocation with respect to conics" by Miss Josephine Chanler.
November 13, 1930: "On metric properties of dual curves" by Mr. C. A. Jackokes.
December 11, 1930: "On the particular solutions of some differential equations" by Mr. R. H. Skidmore.
January 15, 1931: Election of officers; "On the zeros of Bessel's functions" by Mr. E. L. Welker.
February 17, 1931. "Graphical solutions of differential equations" by Miss Ella Marie Meythaler.
March 3, 1931. "The fourth dimension" by Miss Anice Seybold.
March 17, 1931. "Classification of geometries" by Professor A. B. Coble.
April 14, 1931: "Plücker line coordinates" by Mr. W. G. Warnock.

ANICE SEYBOLD, *Secretary.*

The Mathematics Club of New York University.

The mathematics club, organized a few years ago, endeavors to create within its members a desire for individual research in mathematics, and the presentation of this work before the members of the club. Also, topics which do not ordinarily come up in the course of undergraduate study have been presented in talks by various members of the faculty. The club, furthermore, has published during the past year two mathematical journals entitled "*X*" under the editorship of Mr. Reubin Roth. Coaching classes in Trigonometry, College Algebra and Mathematical Analysis have been conducted at regular periods during the year for those students in the University who feel weak in those subjects. Two socials, one each term, were held for the members and their friends.

The officers for 1930–1931, elected at the first meeting of the club in September 1930, were: Mayer I. Birshtein, President; Bertha Berson, Vice President; Sidney Flamm, Secretary; Louis Leitner, Treasurer; Charles K. Payne, Faculty Adviser; Reubin Roth, Editor of "X".

The meetings and programs were as follows:
October 31, 1930: "The relativity controversy" by Mr. C. K. Payne, Instructor in mathematics.
November 14, 1930: "The trisection of angles" by Max Leleiko.
November 28, 1930: "The three famous problems of antiquity" by Sol Feith.
December 5, 1930: "Astronomical calculations by geometry" by Seymour Klanfer.
December 19, 1930: "A solution of the cubic equation" by Abraham Katsh.
February 6, 1931: "Discussion of Fermat's theory of numbers" by Sidney Flamm.
February 20, 1931: "Operational calculus" by Professor Earnest J. Oglesby.
March 6, 1931: "The use of the straight line in mathematics" by Morris Baumel.
April 3, 1931: "Validity and truth in mathematics" by Morris Kline, Instructor in mathematics.
April 10, 1931: "The principle of duality in geometry" by Miss Jeanette Fox.

M. I. BIRSHTEIN, *President.*

Phi Chi Mu, Washington and Jefferson College.

The aim of this society is to promote interest and to stimulate activity in regard to studies pursued in the field of science; to raise the standard of scholarship, afford a reward for diligent work and to furnish an opportunity for the exchange of ideas among students of science at Washington and Jefferson College.

In order that a man be eligible for membership:—(1) He shall be in the process of completing a major in science, (2) he shall have completed the first semester of his junior year at college and (3) he shall have maintained an average of 2 (80%) or better throughout his college course.

Men are recommended for membership by a joint committee of the Heads of the Departments of Mathematics, Physics, Chemistry and Biology.

In order that a man, after election, become an active member of the society, he must present a paper on a topic of scientific interest. At present we have 7 active and 8 elected members.

The officers are elected at the last regular meeting of the school year to hold office during the ensuing year. Those elected May 13th last and holding office during 1930–1931 are: Robert R. Lyle, President; Walter S. Turpin, Secretary-Treasurer.

The meetings are held on the second Tuesday of the month throughout the school year. At these meetings, a paper is presented, followed by a general discussion.

The meetings and programs were as follows:
October 7, 1930: "The significance of 'Mathematics' and 'Science'" by W. S. Turpin.
November 12, 1930: "Topics of interest from 'The Universe around us'" by B. S. Gillespie.
December 9, 1930: "Biology as a science" by R. E. Masters.
January 13, 1931: "Transformations by means of reciprocal radii" and "Elements of plane cubic Cremona transformations" by Dr. H. C. Shaub.
February 10, 1931: "Some phases of mechanical integration-theory of polar planimeters" by R. R. Lyle.
March 10, 1931: "The mathematics of obtaining maximum mobility of aggregate in a concrete mixture and retaining minimum voids in the aggregate" by Dr. C. S. Atchison.
April 14, 1931: "Development in short-wave radio" by W. W. Lamb; "The chemical regulators of the body" by J. P. Proudfit.
May 12, 1931: "Common colds" by A. J. Trapuzzano.

ROBERT R. LYLE, *President*, WALTER S. TURPIN, *Secretary-Treasurer.*

Tulane Mathematics Club.

The officers for 1930–1931 were: Professor Chester G. Jaeger, Chairman; Mrs. Odessa Titsworth, Secretary. The officers are appointed for an indefinite length of time by the chairman of the department of mathematics of Tulane University

There is no regular membership. A card announcing each meeting is sent to those who would probably be interested, and the meeting is announced to advanced classes. Any one is permitted to attend. There are usually between twenty and forty present.

The time of meeting is irregular. There are from two to four meetings each year.

The aim of the club is to present papers on topics not ordinarily covered in courses at this school.

The meetings and programs were as follows:

November 20, 1930: "Elementary theorems on Groups" by Dr. Chester G. Jaeger.

April 30, 1931: "Vector treatment of some geometric problems" by Dr. Nola Lee Anderson.

CHESTER G. JAEGER, *Chairman.*

The Mathematics Club of the New Jersey State Teacher's College.

The officers for 1930–1931 were: Sarah Bogert, '32, President; Dorothy Holman, '32, Vice President; Eleanore Dooley, '32, Secretary; Richard Miller, '32, Treasurer.

The meetings and programs were as follows:

October 8, 1930: "Visualization in geometry" by Mr. A. Bakst, Columbia University, New York City.

October 22, 1930: "Trisection of an angle" by Lucille Drews.

November 12, 1930: "Squaring the circle" by Daniel Goss.

December 10, 1930: "Changing conceptions in secondary mathematics" by Mr. Carrol B. Quaintance, Head of department of mathematics of Cranford High School, Cranford, N. J.

January 14, 1931: "The High School Mathematics Club" by Dorothy Holman and Eleanore Dooley.

January 28, 1931: "Nomographic charts" by Gertrude Blachley.

February 11, 1931: Valentine social.

February 25, 1931: "Mathematics and Religion" by Mr. Harrison E. Webb, Principal of Market Street High School, Newark, N. J.

March 11, 1931: "Mathematical paradoxes" by Mr. A. Bakst.

March 25, 1931: "Peaucellier cells" by Jeanette Curley.

April 22, 1931: "Mathematics in aviation" by Mr. James C. Reddig, Chief engineer for the Grover Loening Aircraft Co., N. Y. C.

May 13, 1931: "The calculus of finite differences" by John Kirschoff.

May 27, 1931: Business meeting and the election of officers.

June 10, 1931: Supper hike.

ELEANORE DOOLEY, *Secretary.*

The Mathematics Club of the University of Akron.

The officers for 1930–1931, elected the first meeting in the fall by a majority vote of the members present, were: Ruth Creighton, President; Beatrice Currie, Vice President; Marjorie Halliwill, Secretary-Treasurer; Elmer Scharenberg, Chairman of the program committee.

The primary aim of the club is to promote, retain and add to the interest of Akron University students in mathematics by having the members, the faculty and outside speakers present special topics and problems before the club. Secondly, the club affords an opportunity for meeting with other students sharing a common interest in mathematics.

The following shall be eligible for membership in the club: (1) All mathematics majors and minors; (2) all engineering, chemistry and physics students; (3) any other students, adjudged by the club to be sufficiently interested in mathematics. To become a member, the candidate must be approved by the majority of members present at the meeting during which the candidate has made known his or her intentions of joining the club. Our present membership consists of sixteen students, three faculty advisors and guests to whom the meetings are open.

The meetings and programs were as follows:

January 8, 1931: "How to tell the day of the week of a certain date" by Dr. S. Selby: "A special problem in connection with the symmetrical functions of roots of an equation" by Marjorie Halliwill; "Fractional equations in which a solution is a zero of the common denominator" by Dr. H. A. Bender.

February 12, 1931: "Preferred numbers" by Mr. Dinger; "Vectors" by Dr. J. Jones.

April 16, 1931: "Graphing by making trigonometric transformations" by Miss Jane Bent; "Integrals in statistics" by Miss Ruth Creighton.

May 14, 1931. "Approximate trisection of angles" by Mr. H. Weisburg; "Surveying and its relation to mathematics" by Mr. Elmer Scharenberg.

The March meeting was held in the form of a trip to Case Observatory in Cleveland. Dr. J. J. Nassau lectured and demonstrated the solar system. Pictures of the sky were shown and the telescope and method of calculating observatory time were explained.

MARJORIE HALLIWILL, *Secretary.*

The Mathematics Club of Butler University.

The officers for 1930–1931, elected by written ballot in May 1930, were Miss Gladys Hawickhorst, President; Miss Willhelmina Feaster, Vice President; Miss Margaret Barker, Secretary; Miss Dione Kerlin, Treasurer.

The purpose of the club is two-fold: To consider and discuss current mathematical topics and to give opportunity to all students in the department to become acquainted.

Membership in the club is granted to all students of the department of mathematics, to those who have been students in the department, and to sponsors. The membership numbered twenty five for the year 1930–1931.

The meetings and programs were as follows:

October 9, 1930: "The evolution of the timepiece" by Ralph Urbain; "Mathematicians distinguished in other fields" by Douglass Brown.

November 6, 1930. "Mathematical tricks" by Mr. W. D. Carnahan of Shortridge High School.

December 18, 1930: Christmas party, mathematical games and puzzles.

January 8, 1931: "Music and mathematics" by Robert Schultz.

February 5, 1931: "Mathematics in nature" by Miss Sturdevant of the Arsenal Technical High School.

March 5, 1931. "The application of higher mathematics in the business world" by Mr. G. C. Elvers, C. E.; "Circle squarers" by Miss Juna M. Lutz, Sponsor.

April 9, 1931: "Non-Euclidean geometry" by Miss Marie Sangernibo of Washington High School; "Mathematics in the training for citizenship" by D. E. Smith (extracts read by Miss Anna K. Suter); "Construction of conic sections by paper folding" by Professor Bowersox.

May 7, 1931: "Egyptian mathematics" by Panoria Apostol: "Development of mathematics in America" by Madonna O'Hair; "Report of the meeting of the Indiana section of the Mathematical Association of America" by Miss Juna M. Lutz; Exhibition of the Chase edition of "The Rhind Papyrus" and of current mathematical periodicals.

June 4, 1931: Picnic.

JUNA M. LUTZ, *Assistant Professor.*

PROBLEMS AND SOLUTIONS

EDITED BY B. F. FINKEL, OTTO DUNKEL, AND H. L. OLSON

Send all communications about Problems and Solutions to B. F. Finkel, Springfield, Mo. All manuscripts should be typewritten, with double spacing and with margins at least one inch wide.

PROBLEMS FOR SOLUTION

Problems containing results believed to be new, or extensions of old results areespecially sought. The editorial work would be greatly facilitated if, on sending in problems, proposers would also enclose any solutions or information that will assist the editors in checking the statements. In general, problems in well-known textbooks or results found in readily accessible sources, will not be proposed as problems for solution in the Monthly. In so far as possible, however, the editors will be glad to assist members of the Association in the solution of such problems.

3516. *Proposed by Norman Miller, Queen's University.*

Prove that

$$\lim_{\substack{a_1\to a\\ a_2\to a\\ \cdots\\ a_{n+1}\to a}} \frac{\begin{vmatrix} 1 & a_1 & a_1^2 & \cdots & a_1^{n-1} & a_1^r \\ 1 & a_2 & a_2^2 & \cdots & a_2^{n-1} & a_2^r \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & a_{n+1} & a_{n+1}^2 & \cdots & a_{n+1}^{n-1} & a_{n+1}^r \end{vmatrix}}{\begin{vmatrix} 1 & a_1 & a_1^2 & \cdots & a_1^n \\ 1 & a_2 & a_2^2 & \cdots & a_2^n \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & a_{n+1} & a_{n+1}^2 & \cdots & a_{n+1}^n \end{vmatrix}} = \frac{r(r-1)\cdots(r-n+1)}{n!}\, a^{r-n}.$$

3517. *Proposed by Morgan Ward, California Institute of Technology.*

Let $\Delta_N(a, \omega)$ denote the determinant

$$\begin{vmatrix} \binom{1}{0} & 1-\omega & 0 & \cdots & 0 & 0 \\ \binom{2}{0} & \binom{2}{1} & 1-a\omega & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & 1-a^{N-3}\omega & 0 \\ \cdots & \cdots & \cdots & \cdots & \binom{N-1}{N-2} & 1-a^{N-2}\omega \\ \binom{N}{0} & \binom{N}{1} & \binom{N}{2} & \cdots & \binom{N}{N-2} & \binom{N}{N-1} \end{vmatrix}.$$

Establish the formula

$$a^{\frac{1}{2}N(N-1)}\Delta_N(a, a^{-N+1}) = \Delta_N(a, a) = (1+a)(1+a+a^2)\cdots(1+a+a^2+\cdots+a^{N-1}).$$

SOLUTIONS

232 [1915, 202; 1931, 228]. *Proposed by E. T. Bell.*

If $F(x)$ is any function of x which vanishes with x, and which, for $0 < |x| \leqq |\xi|$, can be expanded in an absolutely convergent series of positive powers of x, show that a function $f(n)$ may be found, essentially in one way only, such that

$$\int_0^\xi \frac{1}{x} F(x)dx = -\log \prod_{n=1}^{\infty}(1-\xi^n)^{(1/n)f(n)},$$

and find the form of $f(n)$ explicitly in terms of the coefficients in the expansion of $F(x)$. Hence, as particular examples, expand (when possible by the method) e^x as an infinite product, and show that

$$\frac{1}{e} = \prod_{n=1}^{\infty} \left(1 - \frac{1}{2^n}\right)^{(1/n)\phi(n)},$$

where $\phi(n)$ is the totient of n.

Solution by Jack G. Deutsch, Columbia University.

We state the result desired by Professor Bell as follows.

Theorem: If $F(x)$ admits of the development,

$$F(x) = A_1 x + A_2 x^2 + \cdots + A_n x^n + \cdots, \tag{1.1}$$

which converges absolutely for $0 \leqq |x| \leqq |\xi| < 1$, then

$$\int_0^{\xi} \frac{F(x)}{x}\, dx = -\log \prod_{n=1}^{\infty} (1 - \xi^n)^{f(n)/n} \tag{1.2}$$

where $f(n)$ is given by the symbolic formula,

$$f(n) = A_n \left(1 - \frac{1}{A_{p_1}}\right)\left(1 - \frac{1}{A_{p_2}}\right) \cdots \left(1 - \frac{1}{A_{p_s}}\right), \tag{1.3}$$

in which $p_1, \cdots, p_s$ are the distinct primes which divide n and in which it is understood that $A_u A_v$ represents A_{uv} and that (A_u/A_v) represents $A_{(u/v)}$.

Demonstration: We will at first assume the existence of an expansion 1.2 and that we can manipulate the right side of 1.2 in certain ways. We then show that $f(n)$ has the unique representation 1.3. For this purpose the following lemma will be useful.

Lemma: If $f(x)$ satisfies the relation,

$$f(d_1) + \cdots + f(d_r) = A_n,$$

where the A's are any sequence of numbers (not necessarily real) and $d_1, \cdots, d_r$ are the divisors of the integer n, then for integers $f(x)$ has the symbolic representation 1.3.

PROOF: If p is a prime we have

$$\sum_{\beta=0}^{\alpha-1} f(p^\beta) + f(p^\alpha) = A_{p^\alpha}, \text{ or } f(p^\alpha) = A_{p^\alpha} - A_{p^{\alpha-1}}.$$

Hence in symbolic form

$$f(p^\alpha) = A_{p^\alpha}\left(1 - \frac{1}{A_p}\right). \tag{1}$$

We shall now prove that

$$f(p_1^{\alpha_1}p_2^{\alpha_2}\cdots p_s^{\alpha_s}) = f(p_1^{\alpha_1})f(p_2^{\alpha_2})\cdots f(p_s^{\alpha_s}), \tag{2}$$

where the p's are distinct primes, the α's are positive integers or zeros, and where it is understood that on the right each factor is replaced by its symbolic expression. It should be noted that $f(p_i^0)=A_1$. Assume that (2) is true for all values of $s\geqq 1$, and for all positive or zero integers α such that $\alpha_1+\alpha_2+\cdots+\alpha_s\leqq k$. We shall show that it is also true if any α, say α_1, is increased by unity. Consider A_n where $n=p_1^{\alpha_1+1}p_2^{\alpha_2}\cdots p_s^{\alpha_s}$. Then A_n-A_{n/p_1}, when expressed as sums, contains only one term $f(n)$ for which the sum of the exponents can be greater than k. For the remaining terms we can by hypothesis apply the symbolic formula (2). We may then write

$$A_n - A_{n/p_1} = f(p_1^{\alpha_1+1}p_2^{\alpha_2}\cdots p_s^{\alpha_s}) + \sum_{\beta_2=0}^{\alpha_2}\cdots\sum_{\beta_s=0}^{\alpha_s} f(p_1^{\alpha_1+1})f(p_2^{\beta_2}\cdots p_s^{\beta_s}) - f(p_1^{\alpha_1+1})f(p_2^{\alpha_2}\cdots p_s^{\alpha_s}). \tag{3}$$

The sum on the right is precisely

$$A_{p_1^{\alpha_1+1}}\left(1-\frac{1}{A_{p_1}}\right) \text{ times } A_{n/p_1^{\alpha_1+1}}, \text{ or } A_n - A_{n/p_1}.$$

After cancellations we have

$$f(p_1^{\alpha_1+1}p_2^{\alpha_2}\cdots p_s^{\alpha_s}) = f(p_1^{\alpha_1+1})f(p_2^{\alpha_2}\cdots p_s^{\alpha_s}).$$

From (1) the theorem is true for $k=1$, and hence it is always true.

We now expand the right side of 1.2 into a convenient two-way series and equate this series to the expansion for the left side determined by 1.1

$$\begin{aligned}\sum_{k=1}^{\infty}\frac{A_k}{k}\xi^k = {} & f(1)\left[\xi+\frac{\xi^2}{2}+\cdots+\frac{\xi^n}{n}+\cdots\right] \\ & +\frac{f(2)}{2}\left[\xi^2+\frac{\xi^4}{2}+\cdots+\frac{\xi^{2n}}{n}+\cdots\right] \\ & \vdots\qquad\qquad\vdots\qquad\qquad\vdots \\ & +\frac{f(t)}{t}\left[\xi^t+\frac{\xi^{2t}}{2}+\cdots+\frac{\xi^{nt}}{n}+\cdots\right].\end{aligned} \tag{2.1}$$

We now equate coefficients of like powers. For a particular N the only rows that will contain a ξ^N-term are those for which t is a divisor of N. It is clear that we have $f(d_1)+\cdots+f(d_r)=A_N$ where the d's are the divisors of N. The lemma shows that $f(n)$ has the unique formulation 1.3 provided the expansion 1.2 and the above manipulations are valid. It is these points that we need settle to complete the prooof of the theorem.

Lemma: If the series,

$$\sum_1^\infty A_n x^n$$

converges absolutely for $x=\xi(|\xi|<1)$, then the series

$$2.2 \qquad \sum_{n=1}^{\infty}\left(\sum_{j=1}^{n}|A_j|\right)x^n$$

converges for $x=|\xi|$.

Consider the absolutely convergent series,

$$2.3 \qquad \sum_1^\infty |A_n|\frac{|\xi|^n}{1-|\xi|}.$$

Expand it into the two-way series,

$$\begin{aligned}\sum_1^\infty |A_n|\frac{|\xi|^n}{1-|\xi|} = {} & |A_1|\,[\,|\xi|+|\xi|^2+|\xi|^3+\cdots\,]\\ & +|A_2|\,[\,|\xi|^2+|\xi|^3+\cdots\,]\\ & +|A_3|\,[\,|\xi|^3+\cdots\,]\\ & +\cdots.\end{aligned}$$

Since each row and each column is absolutely convergent the sum of the columns will yield a convergent series which is precisely 2.2 with $x=|\xi|$.

Now let $f(n)$ be given by 1.3. We have surely that

$$|f(n)| \leqq \sum_{j=1}^{n}|A_j|$$

for all n. By virtue of the preceding lemma the two-way series of 2.1 has a meaning and its sum is the right side of 1.2. We can calculate the value of the right side of 2.1 by collecting the terms according to the powers of ξ. Now, because of the formula for $f(n)$, we will have the equality given in 2.1 so that 1.2 is valid. This completes the proof of the theorem.

If we take $A_n=n$, we have that $f(n)$ is the Euler function, $\phi(n)$. In this case if we take $\xi=1/2$, we have the example given by Professor Bell, namely,

$$\frac{1}{e}=\prod_{n=1}^{\infty}\left(1-\frac{1}{2^n}\right)^{\phi(n)/n}.$$

A Note by Otto Dunkel. Another proof of 1.3 of page 540 is as follows:

Let $n=p_1^{\alpha_1}p_2^{\alpha_2}\cdots p_s^{\alpha_s}$, and let C_i denote the class of all divisors of such integers as $n/p_1p_2,\cdots,p_i$ of which there are $\binom{s}{i}$. The class C_0 contains the single integer n, each of the other classes contain unity. All the divisors of n are contained in the group of classes $C_0, C_1, \cdots, C_s$, but there are repetitions. Consider the number of times the integer $p_1^{\alpha_1}p_2^{\alpha_2}\cdots p_i^{\alpha_i}p_{i+1}^{\beta_{i+1}}\cdots p_{i+r}^{\beta_{i+r}}$ occurs

in each class, where $\beta_k < \alpha_k$, $i+r \leqq s$. In C_j this integer will appear as a divisor of $n/p_{h_1}p_{h_2}\cdots p_{h_j}$, if no one of $p_1, p_2, \cdots, p_i$ is in the denominator of this fractional form. Hence it occurs $\binom{s-i}{j}$ times in C_j. Since

$$\sum_{j=1}^{s-i}(-1)^{j+1}\binom{s-i}{j} = 1,$$

we affix the sign $(-1)^{j+1}$ to C_j, and then the set of integers in

$$n + C_1 - C_2 + C_3 - \cdots + (-1)^{s+1} C_s$$

contains after cancellations each divisor of n once and only once. Therefore

$$A_n = f(n) + \sum f(x_1) - \sum f(x_2) + \cdots + (-1)^{s+1}\sum f(x_s),$$

where x_j runs through the integers in C_j. Thus

$$f(n) = A_n - \sum A_{n/p_i} + \sum A_{n/p_ip_j} - \cdots + (-1)^s A_{n/p_1p_2\cdots p_s}.$$

Or in symbolic form

$$f(n) = A_n\left(1 - \frac{1}{A_{p_1}}\right)\left(1 - \frac{1}{A_{p_2}}\right)\cdots\left(1 - \frac{1}{A_{p_s}}\right).$$

315 [1915, 309]. *Proposed by H. S. Uhler.*

A solid, homogeneous, right, circular cylinder is allowed to move from rest down a circular cylindrical track which is concave upwards. Find the ratio of the radius of the track to the radius of the cylinder when the time of descent through a finite arc to the bottom is the same for the extreme cases of no slipping and zero friction. Show also that the same relation holds for a sphere descending a cylindrical or spherical surface.

Solution by the Proposer.

Case 1. *Adequate friction.* When there is no slipping we may take moments about the instantaneous axis of rotation, that is, about the (horizontal) line of contact of the fixed and rolling bodies. Then

$$I\frac{d^2\phi}{dt^2} = agm\sin\theta, \tag{1}$$

where a, m, and I denote respectively the radius, the mass, and the moment of inertia (with respect to the instantaneous axis) of the rolling body. g symbolizes the acceleration of gravity. θ represents the angle made with the vertical by the plane which, at any instant, passes through the axis of the fixed cylinder and the center of mass of the rolling body. $d\phi/dt$ stands for the angular speed of the rolling body about the instantaneous axis. Then, if b denotes the radius of the fixed cylinder, we have

$$a\frac{d\phi}{dt} = -(b-a)\frac{d\theta}{dt}.$$

Hence, by substituting in equation (1), we have also

$$\frac{d^2\theta}{dt^2} = -C_1^2 \sin\theta \tag{2}$$

where, for brevity,

$$C_1^2 \equiv \frac{a^2gm}{I(b-a)}.$$

Integrating differential equation (2) once, under the condition that the movable body starts from rest when $\theta=\theta_0$, we find

$$\frac{d\theta}{dt} = C_1[2(\cos\theta - \cos\theta_0)]^{1/2}.$$

Therefore,

$$t_1 = \frac{1}{\sqrt{2}\cdot C_1}\int_0^{\theta_0} \frac{d\theta}{(\cos\theta - \cos\theta_0)^{1/2}}, \tag{3}$$

where t_1 symbolizes the time to roll from $\theta=\theta_0$ to $\theta=0$.

Case 2. *Zero friction.* It will be found at once that

$$t_2 = \frac{1}{\sqrt{2}\cdot C_2}\int_0^{\theta_0} \frac{d\theta}{(\cos\theta - \cos\theta_0)^{1/2}}, \tag{4}$$

where $C_2^2 \equiv g/(b-a)$.

By hypothesis $t_1=t_2$; hence, expressions (3) and (4) now give

$$C_1 = C_2,$$

that is,

$$I = a^2m. \tag{5}$$

Let k denote the radius of gyration of the moving body with respect to a horizontal line through the center of mass of this body then, by the theorem of parallel axes, we have

$$I = m(a^2 + k^2). \tag{6}$$

Combining relations (5) and (6), we get $k=0$ which means that the radius of the moving body must be zero. In other words, the conditions specified can not be fulfilled by bodies of finite radii. [If my memory is trustworthy I obtained a finite answer by the same processes just before this problem was submitted for publication. Hence I must have made a mistake in algebra at that time. Nevertheless, the chief point was to get the same integral in both cases and then to eliminate it.]

Also solved by H. M. Dadourian, William Hoover, J. B. Reynolds, and F. L. Wilmer.

NOTES AND NEWS

Readers are invited to contribute to the general interest of this department by sending items to Professor H. W. Kuhn, Ohio State University, Columbus, Ohio.

Through the courtesy of Professor W. F. Shenton of the American University, the Library of the Mathematical Association now possesses a complete set of the *Mathematical Visitor* published by Artemas Martin during the years 1877–1894, and of the *Mathematical Magazine* published by him during the years 1882–1910. This includes a copy of the very rare first edition of Volume 1, Number 1 of the *Mathematical Visitor*. It will be of interest to the members of the Association to know that the American University possesses the files of the *Visitor* and the *Mathematical Magazine* and that colleges or individuals who wish to have these magazines in their libraries, or who wish to fill out incomplete sets, may purchase them through Professor Shenton.

Princeton University announces that it has now made provision for work towards advanced degrees in mathematical physics. During the fall term of 1931–32, graduate courses in this field will be offered by Professors E. P. Adams, J. von Neumann, E. P. Wigner, E. U. Condon, and H. P. Robertson. Dr. P. A. M. Dirac, of Cambridge, will lecture on the relativistic formulation of quantum mechanics during the first part of this term.

Dr. Clifford Bell has been promoted to an assistant professorship of mathematics at the University of California at Los Angeles.

Dr. L. W. Cohen has been appointed assistant professor of mathematics at the University of Kentucky.

Assistant Professor T. F. Cope has been promoted to a professorship of mathematics at Marietta College.

Dr. F. W. Doermann, of New York University, has been promoted to an assistant professorship of physics.

Professor W. W. Elliott, of Duke University, has been granted sabbatical leave for the first semester of 1931–1932. He will spend most of this time at Brown University.

Dr. D. A. Flanders, of New York University, has been promoted to an assistant professorship.

Assistant Professor Raymond Garver, of the University of California at Los Angeles, has been promoted to an associate professorship of mathematics.

Professor Alfred Hume, of Southwestern University, Memphis, has been appointed president of Branham and Hughes Military Academy, Spring Hill, Tennessee.

Professor J. A. Hurry, of Western State College, Gunnison, Colorado, has been appointed head of the department of physics at San Antonio Junior College.

Dr. N. H. McCoy has been appointed to an assistant professorship at Smith College.

Associate Professor W. M. Miller, of Marquette University, has been appointed to an assistant professorship at Tufts College.

Dr. D. C. Morrow has been promoted to an assistant professorship at the College of the City of Detroit.

Dr. Gordon Pall has been appointed lecturer in mathematics at McGill University.

Dr. Saul Pollock, of the University of California, has been appointed to an assistant professorship of mathematics at the Indiana State Teachers College at Terre Haute.

Professor G. E. Raynor, of the University of Oklahoma, has been appointed assistant professor of mathematics at Lehigh University.

Associate Professor O. H. Rechard, of the University of Wyoming, has been promoted to a professorship of mathematics.

Associate Professor C. N. Reynolds, of West Virginia University, has been promoted to a professorship of mathematics.

Dr. John H. Roberts, of the University of Texas, has been appointed to an assistant professorship of mathematics at Duke University.

Associate Professor F. L. Wren has been promoted to a professorship of the teaching of mathematics at the George Peabody College for Teachers.

Dr. E. Kathryn Wyant has been appointed professor of mathematics at the Northeastern State Teachers College, Tahlequah, Oklahoma.

The following appointments to instructorships in mathematics are announced:

Duke University, Dr. Ruth W. Stokes.
Johns Hopkins University, Mr. G. R. Trott.
Lehigh University, Mr. S. S. Cairns.
Princeton University, Mr. Jack Levine.
Temple University, Mr. J. A. Clark.

Professor G. H. Cresse, of the University of Arizona, died on May 3, 1931.

PLANE TRIGONOMETRY

By

Raymond W. Brink, Ph.D.

Prof. of Mathematics, University of Minnesota

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In the year 1925, the MATHEMATICAL ASSOCIATION OF AMERICA established a prize of one hundred dollars for the best expository paper published in English during successive periods of five years by a member of the Association.

The purpose of the prize is to stimulate expository contributions in mathematical journals. The award does not apply to books, although the CARUS MONOGRAPHS are expository in character and on this score might be included. They carry their own reward in the form of a cash honorarium to each author.

The prize will be awarded hereafter every three years. The last award was in December, 1929, to Professor T. H. Hildebrandt. The next award will be in December, 1932 for the period of 1929-1931.

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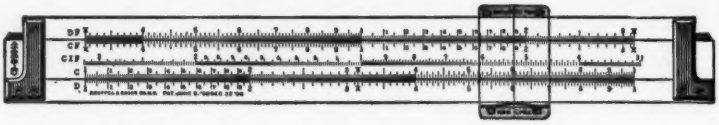

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Sixteenth Annual Meeting of the Association, New Orleans, Louisiana, Dec. 30-31, 1931.

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ILLINOIS, Peoria, May 1-2.
INDIANA, Muncie, May 1-2.
IOWA, Davenport, May 1-2.
KANSAS, Topeka, Jan. 24.
KENTUCKY, Lexington, May 9.
LOUISIANA-MISSISSIPPI, Natchitoches, La., March 13-14.
MARYLAND-DISTRICT OF COLUMBIA-VIRGINIA, Richmond, Va., May 9.
MICHIGAN, Ann Arbor, March 21.
MINNESOTA, St. John's University, Collegeville, May 16.
MISSOURI, St. Louis, November.
NEBRASKA, Lincoln, May 8.
OHIO, Columbus, April 2.
PHILADELPHIA, Philadelphia, Nov. 28.
ROCKY MOUNTAIN, Boulder, Colo., April 17-18.
SOUTHEASTERN, Auburn, Ala., April 24-25.
SOUTHERN CALIFORNIA, Occidental College, Los Angeles, March 21.
TEXAS, Fort Worth, Jan. 31.

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AYRES, Asst. Prof. W. L., Ph.D. (Pennsylvania) Univ. of Michigan, Ann Arbor, Mich. *1225 White St.*

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BARR, Asst. Prof. C. F., M.S. (Chicago) Univ. of Wyoming, Laramie, Wyo. *515 S. 8th St.*
BARRETT, A. J., A.B. (Arkansas) Teacher, High School, Jamaica, N. Y. *8620–162nd St.*
BARRICK, Prof. D. L., M.S. (Oklahoma) 507½ Baltimore Ave., Muskogee, Okla.
BARROW, Prof. D. F., Ph.D. (Harvard) Univ. of Georgia, Athens, Ga. *260 Cherokee Ave.*
BARTKY, Asst. Prof. WALTER, Ph.D. (Chicago) Mathl. Astr., Univ. of Chicago, Chicago, Ill.
BARTON, Prof. HELEN, Ph.D. (Johns Hopkins) Head of Dept., North Carolina Coll., Greensboro, N. C. *1027 Spring Garden St.*
BASOCO, Asst. Prof. M. A., Ph.D. (Calif. Inst. of Tech.) Univ. of Nebraska, Lincoln, Nebr. *Dept. of Math.*
BASSLER, KATHERINE R., A.M. (Bryn Mawr) Teacher, Bryn Mawr School for Girls, Baltimore, Md. *On leave 1931-32, U. S. Natl. Museum, Washington, D. C.*
BATCHELDER, Asso. Prof. P. M., Ph.D. (Harvard) Pure Math., Univ. of Texas, Austin, Tex. *808 W. 22nd St.*
BATEMAN, Prof. HARRY, Ph.D. (Johns Hopkins) California Inst. of Tech., Pasadena, Calif.
BATEN, Asst. Prof. W. D., Ph.D. (Michigan) Univ. of Michigan, Ann Arbor, Mich. *914 S. State St.*
BATTIG, LEON, A.M. (Wisconsin) Instr., Extension Div., Univ. of Wisconsin, Milwaukee, Wis. *2542 N. Buffum St.*
BAUER, Prof. G. N., Ph.D. (Columbia) Statistics, Univ. of New Hampshire, Durham, N. H.
BAUER, L. A., Ph.D. (Berlin) Director Emeritus, Dept. of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C. *5241 Broad Branch Rd.*
BAUER, L. M., A.B. (Oakland City Coll.) Teacher, Menaul School, Albuquerque, N. Mex.
BAUR, Asso. Prof. P. E., M.S. (Michigan) Math. and Drawing, Baldwin-Wallace Coll., Berea, Ohio. *114 E. Grand St.*
BAXTER, W. E., A.M. (Kentucky) Grad. Asst., Univ. of Kentucky, Lexington, Ky. *McVey Hall.*

BAY, J. C. Librarian, The John Crerar Library, Chicago, Ill. *86 E. Randolph St.*
BAYS, Dr. SÉVÉRIN. Prof. ord., Faculté des Sciences, Univ. de Fribourg, Bethlehem, Fribourg, Switzerland.
BEAR, A. W., B.S. (Marquette) Instr., Marquette Univ., Milwaukee, Wis. *2016 W. Scott St.*
BEATLEY, Asso. Prof. RALPH, A.M. (Columbia) Harvard Grad. School of Educ., Cambridge, Mass.
BEATTY, Asst. Prof. H. M., A.M. (Ohio State) Ohio State Univ., Columbus, Ohio. *200 Tibet Rd.*
BEATTY, Prof. SAMUEL, Ph.D. (Toronto) Univ. of Toronto, Toronto, Ont., Can.
BEATY, Asso. Prof. E. B., A.M. (California) Oregon Agric. Coll., Corvallis, Ore. *21 N. 27th St.*
BEAVER, R. A., A.M. (Columbia) Instr., State Coll. for Teachers, Albany, N. Y.
BECKWITH, Prof. ETHELWYNN R. (Mrs. W. E.), Ph.D. (Radcliffe) Head of Dept., Milwaukee Downer Coll., Milwaukee, Wis.
BEENKEN, MAY M., Ph.D. (Chicago) Head of Dept., State Teachers Coll., Oshkosh, Wis.
BEETLE, Prof. R. D., Ph.D. (Princeton) Dartmouth Coll., Hanover, N. H.
BEISEL, Asst. Prof. B. R., B.S. (Allegheny) Allegheny Coll., Meadville, Pa. *345 Highland Ave.*
BELL, Asst. Prof. CLIFFORD, Ph.D. (California) Univ. of California at Los Angeles, Los Angeles, Calif. *2414 S. Burnside Ave.*
BELL, Prof. E. T., Ph.D. (Columbia) California Inst. of Tech., Pasadena, Calif.
BELL, LOIS E., A.M. (Kansas) Instr., Independence Jr. Coll., Independence, Kans. *610 N. Ninth St.*
BELL, Prof. TALMON, A.B. (Sterling) Sterling Coll., Sterling, Kans.
BELLAMY, B. C., B.S.C.E. (Wyoming) Civil Engineer, Laramie, Wyo.
BENANDER, C. A., A.B. (Harvard) 1651 Crawford Rd., Cleveland, Ohio.
BENDER, Asst. Prof. H. A., Ph.D. (Illinois) Univ. of Akron, Akron, Ohio.
BENEDICT, Pres. H. Y., Ph.D. (Harvard) Univ. of Texas, Austin, Tex.
BENEDICT, Prof. SUZAN R., Ph.D. (Michigan) Smith College, Northampton, Mass. *12 Barrett Pl.*
BENEDICTA, Sister M. (BOYLE), B.S. (Canisius) Teacher, Villa Maria Coll., Erie, Pa. *W. 8th St.*
BENNETT, Prof. A. A., Ph.D. (Princeton) Brown Univ., Providence, R. I.
BENNETT, Prof. J. L., A.M. (Kansas) Physics, Ottawa Univ., Ottawa, Kans.
BENNETT, Asst. Prof. THEODORE, Ph.D. (Illinois) Univ. of Wisconsin, Madison, Wis.
BERGER, EDLA G., A.M. (Minnesota) Mathematician, Actuarial Dept., Equitable Life Assurance Soc., New York, N. Y. *1411-161st St., Beechhurst, L. I., N. Y.*
BERGSTRESSER, C. A., A.M. (Lafayette), M.S. (Pennsylvania) Head of Dept., Jamaica High School, New York, N. Y. *780 St. Marks Ave., Brooklyn, N. Y.*
BERKELEY, L. M., A.M. (Virginia) 36 W. 91st St., New York, N. Y.
BERNSTEIN, Prof. B. A., Ph.D. (California) Univ. of California, Berkeley, Calif. *2785 Shasta Rd.*
BERRY, Prof. E. M., Ph.D. (Iowa) Lynchburg Coll., Lynchburg, Va. *504 Westwood, Ave.*
BERRY, Asso. Prof. GRACE E., A.M. (Mount Holyoke) Pomona Coll., Claremont, Calif. *353 W. 11th St.*
BERRY, Prof. W. J., A.M. (Harvard) Poly. Inst. of Brooklyn, Brooklyn, N. Y. *224 St. John's Pl.*
BERRY, W. J., M.S. (Colorado) Metropolitan Life Ins. Co., New York, N. Y. *609 W. 137 St.*
BERT, Prof. O. F. H., A.M. (Geneva) Washington and Jefferson Coll., Washington, Pa. *28 N. Lincoln St.*
BERTRAND, Sister M. (WALTON), Ph.D. (Fordham) Teacher, Marywood Coll., Scranton, Pa.
BETTINGER, Asst. Prof. A. K., A.M. (Wisconsin) Creighton Univ., Omaha, Nebr.
BETZ, WILLIAM, A.M. (Rochester) Vice-Prin., East High School, Rochester, N. Y. *652 Melville St.*
BEVERIDGE, Prof. H. R., Ph.D. (Illinois) Monmouth Coll., Monmouth, Ill. *316 S. 9th St.*
BIBB, Asst. Prof. S. F., M.S. (Chicago) Armour Inst. of Tech., Chicago, Ill.
BICKERSTAFF, Asst. Prof. T. A., A.M. (Mississippi) Univ. of Mississippi, University, Miss. *Box 23.*
BIGBEE, J. A., B.S. (Drury) High School, Little Rock, Ark. *3110 Battery St.*
BILL, Prof. E. G., Ph.D. (Yale) Dean of Freshmen, Director of Admissions, Dartmouth Coll., Hanover, N. H.
BINGLEY, Prof. G. A., A.M. (Princeton) St. John's Coll., Annapolis, Md. *Brice House.*
BIRCHBY, W. N., A.M. (Colo. Coll.) Instr., California Inst. of Tech., Pasadena, Calif.
BIRCHENOUGH, Prof. HARRY, A.M. (Columbia) State Coll. for Teachers, Albany, N. Y. *687 Hudson Ave.*

BIRKHOFF, Prof. G. D., Ph.D.(Chicago) Harvard Univ., Cambridge, Mass. *984 Memorial Dr.*
BLACK, Asst. Prof. FLORENCE L., Ph.D. (Kansas) Univ. of Kansas, Lawrence, Kans. *1300 Louisiana St.*
BLACK, L. G., A.M. (Colorado) Instr., Purdue Univ., W. Lafayette, Ind. *202 North St.*
BLACK, Prof. L. T., A.M. (Michigan) Ashland Coll., Ashland, Ohio.
BLAIR, Prof. HAROLD, A.M. (Michigan) Western State Teachers Coll., Kalamazoo, Mich. *1220 Academy St.*
BLAIR, Asst. Prof. LEORA, A.M. (Chicago) State Normal Coll., Natchitoches, La.
BLAIR, Asst. Prof. R. V., A.M. (Peabody) Vanderbilt Univ., Nashville, Tenn.
BLAIR, VEVIA, A.M. (Columbia) Teacher, Horace Mann School, New York, N. Y. *509 W. 121 St.*
BLAKE, ARCHIE, M.S. (Chicago) Mathematician, U. S. Coast and Geodetic Survey, Washington, D. C. *212 A Street S.E.*
BLAU, L. W., Ph.D. (Texas) Director of Geophysical Research, Humble Oil and Refining Co., Houston, Tex. *2027 Colquitt Ave.*
BLICHFELDT, Prof. H. F., Ph.D. (Leipzig) Stanford Univ., Stanford University, Calif. *Box 875.*
BLISS, Prof. G. A., Ph.D. (Chicago) Univ. of Chicago, Chicago, Ill.
BLUE, Prof. A. H., Ph.D. (Iowa) Western Union Coll., LeMars, Iowa.
BLUMBERG, A. A., A.B. (Texas) Instr., A. and M. Coll., College Station, Tex. *Box 149, Faculty Exchange.*
BLUMBERG, Prof. HENRY, Ph.D. (Göttingen) Ohio State Univ., Columbus, Ohio. *76 E. Blake Ave.*
BLUMENTHAL, L. M., Ph.D. (Johns Hopkins) Instr., Rice Inst., Houston, Tex.
BOBERTZ, W. E., M.S.E. (Michigan) Research Engineer, Union Switch and Signal Co., Swissvale, Pa. *3148 Woodward Ave., Detroit, Mich.*
BOEDER, PAUL, A.M. (Pennsylvania) Univ. of Göttingen, Göttingen, Germany. *Weenderlandstr. 46.*
BOGARD, Prof. A., A.M. (Chicago) Coll. of St. Teresa, Winona, Minn. *1075 W. 7th St.*
BOHNERT, J. I., Jr. Student, Carnegie Inst. of Tech., Pittsburgh, Pa. *109 Grandview Ave., Mt. Washington Sta.*
BOLKS, STANLEY, M.S. (Iowa State Coll.) Instr., Purdue Univ., W. LaFayette, Ind. *153 S. Sheetz St.*
BOLTON, R. W., E.E. (Illinois) 2000 Tenth St., Glendale, Calif.
BOND, Prof. J. D., Ph.D. (Michigan) Univ. of Tennessee, Knoxville, Tenn.
BOND, Pres. O. J., LL.D. (South Carolina) The Citadel, The Milit. Coll. of South Carolina, Charleston, S. C.
BOND, Prof. W. M., A.M. (Columbia) Waynesburg Coll., Waynesburg, Pa. *Fort Jackson Hotel.*
BOND, W. V. Student, Univ. of Göttingen, Göttingen, Germany. *Weenderlandstr. 46.*
BOOTHROYD, Prof. S. L., M.S. (Colo. State Coll.) Astr. and Geodesy, Cornell Univ., Ithaca, N. Y.
BOREL, ÉMILE, Docteur es Sc. (Paris) Prof. à la Faculté des Sciences de Paris, Paris, France. *32 rue du Bac, Paris VII.*
BORGER, Prof. R. L., Ph.D. (Chicago) Ohio Univ., Athens, Ohio. *Fenzel Apts.*
BORGMAN, W. M., Jr. B.S. (Michigan) Instr., Coll. of the City of Detroit, Detroit, Mich.
BORTOLOTTI, Prof. ETTORE, Dottore in mat. (Bologna) Univ. of Bologna, Bologna, Italy. *100 Via Maggiore.*
BOWDEN, Prof. JOSEPH, Ph.D. (Yale) Adelphi Coll., Garden City, N. Y. *33 Exeter St., Brooklyn, N. Y.*
BOWER, JULIA W., A.M. (Syracuse) Grad. Student, Univ. of Chicago, Chicago, Ill.
BOWER, O. K., Ph.D. (Illinois) Instr., Univ. of Illinois, Urbana, Ill. *714 Arlington Ct., Champaign, Ill.*
BOWERSOX, Asso. Prof. E. R., E.E. (Iowa) Physics, Butler Univ., Indianapolis, Ind.
BOWLES, Asst. Prof. C. F., Ph.D. (Chicago) State School of Mines, Rapid City, S. Dak. *Box 922.*
BOYCE, M. G., Ph.D. (Chicago) Instr., Adelbert Coll., Western Reserve Univ., Cleveland, Ohio.
BOYD, ELIZABETH N., A.M. (Columbia) Instr., Math. and Chem., Greenbrier Coll., Lewisburg, W. Va.
BOYD, Dean P. P., Ph.D. (Cornell) Head of Dept., Univ. of Kentucky, Lexington, Ky. *119 Waller Ave.*
BRADLEY, A. D., A.M. (Teachers Coll., Columbia) Instr., Hunter Coll., New York, N.Y. *8 S. Broadway, Dobbs Ferry, N. Y.*
BRADLEY, Asso. Prof. H. C., B.S. (Mass. Inst. of Tech.) Mass. Inst. of Tech., Cambridge, Mass.

BRADSHAW, Prof. J. W., Ph.D. (Strassburg) Univ. of Michigan, Ann Arbor, Mich. *1304 Cambridge Rd.*

BRAMBLE, Prof. C. C., Ph.D. (Johns Hopkins) Math. and Mech., Postgraduate School, U. S. Naval Acad., Annapolis, Md. *3 Fifth St.*

BRAND, Prof. LOUIS, Ph.D. (Harvard) Univ. of Cincinnati, Cincinnati, Ohio. *2605 University Ct.*

BRANDEBERRY, Prof. J. B., A.M. (Ohio State) Univ. of the City of Toledo, Toledo, Ohio.

BRANDNER, F. A., A.M. (Chicago) Instr., Iowa State Coll., Ames, Iowa. *Dept. of Math.*

BRATTON, Prof. W. A., Sc.D. (Williams) Dean and Prof., Whitman Coll., Walla Walla, Wash. *570 Boyer Ave.*

BRAUN, ANTHONY, A.M. (Catholic Univ.) Franciscan Monastery, Washington, D. C.

BRAY, Asst. Prof. H. E., Ph.D. (Rice) Rice Institute, Houston, Tex.

BRECKENRIDGE, W. E., A.M. (Yale) Stuyvesant High School, New York, N. Y. *345 E. 15th St.*

BREIT, Prof. GREGORY, Ph.D. (Johns Hopkins) Physics, New York Univ., New York, N. Y.

BRENKE, Prof. W. C., Ph.D. (Harvard) Univ. of Nebraska, Lincoln, Nebr. *1250 S. 21st St.*

BREWSTER, Asst. Prof. J. A., A.B. (Harvard) Coll. of the City of New York, New York, N. Y. *Hudson View Gardens, 183 and Pinehurst Ave.*

BREZLER, W. J., A.M. (Grove City) Wartburg Normal Coll., Waverly, Iowa.

BRINK, Prof. R. W., Ph.D. (Harvard) Univ. of Minnesota, Minneapolis, Minn. *55 Williams Ave. S.E.*

BRISTOL, W. A., A.M. (Pennsylvania) Instr., Temple Univ., Philadelphia, Pa.

BRITTON, JACK, A.B. (Clark) Engg. Math., Univ. of Colorado, Boulder, Colo. *1145 Pennsylvania Ave.*

BRIXEY, Asst. Prof. J. C., A.M. (Oklahoma) Univ. of Oklahoma, Norman, Okla. *417 Elm St.*

BROCKETT, Asso. Prof. GERTRUDE L., A.M. (Brown) Houghton Coll., Houghton, N. Y.

BRODIE, Prof. W. M., M.E. (Va. Poly. Inst.), A.M. (Columbia) Virginia Poly. Inst., Blacksburg, Va.

BROMWELL, ALICE, A.M. (Nebraska) Instr., Monticello Seminary, Godfrey, Ill.

BROOKE, Prof. W. E., A.M. (Nebraska) Math. and Mech., Univ. of Minnesota, Minneapolis, Minn.

BROWN, A. B., Ph.D. (Harvard) Instr., Columbia Univ., New York, N. Y. *2940 Broadway, Room 605.*

BROWN, Asst. Prof. B. H., Ph.D. (Harvard) Dartmouth Coll., Hanover, N. H. *1 S. Balch Rd.*

BROWN, D. M., A.B. (Illinois) Asst., Univ. of Illinois, Urbana, Ill. *160 Math. Bldg.*

BROWN, E. C., A.M. (Maine) Worcester Poly. Inst., Worcester, Mass. *25 Schussler Rd.*

BROWN, Prof. E. W., D.Sc. (Cambridge, Eng.) Yale Univ., New Haven, Conn. *116 Everet St.*

BROWN, G. M., M.Sc. (Univ. of Leeds, England) 3215 N. Keating Ave., Chicago, Ill.

BROWN, Prof. H. S., M.S. (Lafayette) Hamilton Coll., Clinton, N. Y.

BROWN, Prof. LILLIAN O., A.M. (Columbia) Hood Coll., Frederick, Md.

BROWN, Prof. MYRTLE C., A.M. (Texas) Teachers Coll., Denton, Tex. *1415 W. Oak St.*

BROWN, O. E., Ph.D. (Chicago) Instr., Case School of Appl. Sci., Cleveland, Ohio. *1754 Noble Rd., E. Cleveland, Ohio.*

BROWN, Asso. Prof. T. H., Ph.D. (Yale) Business Statistics, Grad. School of Bus. Admin., Harvard Univ., Cambridge, Mass. *25 Meadow Way.*

BROWNE, Asso. Prof. E. T., Ph.D. (Chicago) Univ. of North Carolina, Chapel Hill, N. C. *730 E. Franklin St.*

BRUCE, C. W., A.M. (Virginia) Grad. Student, Univ. of Virginia, University, Va.

BRUCE, Prof. R. E., Ph.D. (Boston Univ.) Boston Univ., Boston, Mass.

BRYAN, Asso. Prof. N. R., Ph.D. (Columbia) Univ. of Maine, Orono, Me. *4 University Pl.*

BRYANT, E. S., Ed.M. (Harvard) Acting Prin., High School, Everett, Mass. *53 Lexington St.*

BUCHANAN, Prof. DANIEL, Ph.D. (Chicago) Dean of Faculty of Arts and Sciences, Univ. of British Columbia, Vancouver, B.C., Can.

BUCHANAN, Prof. H. E., Ph.D. (Chicago) Tulane Univ., New Orleans, La.

BUCHANAN, Asso. Prof. SCOTT, Ph.D. (Harvard) Philosophy, Univ. of Virginia, University, Va.

BUELL, C. E., A.B. (Oberlin) Grad. Student, Ohio State Univ., Columbus, Ohio. *47 E. Woodruff Ave.*

BULLARD, Prof. J. A., Ph.D. (Clark) Math. and Mech., Univ. of Vermont, Burlington, Vt. *110 Summit St.*

BULLARD, N. H., B.S. (Georgia) Head of Dept., High School, Ft. Pierce, Fla. *115 N. 12th St.*

BULLITT, W. M., B.S. (Princeton), LL.B. (Louisville) 1710–1711 Inter Southern Bldg., Louisville, Ky.

BUMER, Asst. Prof. C. T., Ph.D. (Ohio State) Kenyon Coll., Gambier, Ohio.
BUNYAN, Asst. Prof. L. H., Ph.D. (Wisconsin) Rutgers Univ., New Brunswick, N. J. *Dept. of Math.*
BURDICK, R. D., A.M. (Columbia) Instr., Coll. of the City of New York, New York, N. Y. *6083 Broadway.*
BURGESS, H. T., Ph.D. (Yale) Morningside Drive, Morningside, Milford, Conn.
BURGESS, R. W., Ph.D. (Cornell) Chief Statistician, Western Electric Co., New York, N. Y. *195 Broadway.*
BURINGTON, R. S., Ph.D. (Ohio State) Instr., Case School of Appl. Sc., Cleveland, Ohio *3417 Beechwood Ave., Cleveland Heights, Ohio.*
BURKE, J. G., A.M. (Mt. St. Mary's) Vice Pres., Mt. St. Mary's Coll., Emmitsburg, Md.
BURKETT, Asst. Prof. F. J. H., Ph.D. (New York Univ.) Union Coll., Schenectady, N. Y.
BURLEY, J. F., Civil Engineer, Washington, D. C. *3010 Wisconsin Ave.*
BURNAM, Prof. J. E., A.M. (Texas) Simmons Univ., Abilene, Tex.
BURNEY, M. SUE, A.M. (Chicago) 20 Rock Ridge, Greenwich, Conn.
BURROWS, W. R., B.S. (Chicago) Draftsman, Standard Oil Co. (Ind.) Whiting, Ind. *8222 Drexel Ave., Chicago, Ill.*
BURWELL, W. R., Ph.D. (Oxford, England) Cuyahoga Bldg., Cleveland, Ohio.
BUSHEY, Asst. Prof. J. H., Ph.D. (Michigan) Math. and Ins., Hunter Coll., New York, N. Y. *Park Ave. and 68th St.*
BUSHYAGER, G. R., A.M. (Pennsylvania State) Instr., Univ. of Detroit, Detroit, Mich.
BUSSEY, Asst. Dean and Prof. W. H., Ph.D. (Chicago) Univ. of Minnesota, Minneapolis, Minn. *106 Folwell Hall.*
BUTLER, J. F., A.M. (St. Louis Univ.) St. Ignatius Coll., Chicago, Ill. *1076 W. Roosevelt Rd.*
BUTLER, L. G., A.M. (Oregon) Instr., State Coll. of Washington, Pullman, Wash. *802 Linden Ave.*
BUTTERFIELD, Prof. A. D., A.M. (Columbia) Coll. of Eng., Univ. of Vermont, Burlington, Vt. *25 Colchester Ave.*
BUTTERFIELD, D. D., A.M. (Princeton) Instr., Phillips Exeter Acad., Exeter, N. H. *Webster Hall.*
BUXTON, Prof. W. H., A. M. (Oregon) Whitworth Coll., Spokane, Wash.
BYRD, SAM, A.M. (Arkansas) Teacher, Central High School, Tulsa, Okla. *1344 S. Birmingham Ave.*
BYRNE, Asso. Prof. W. E., Ph.D. (Rensselaer) Virginia Milit. Inst., Lexington, Va.
BYRNES, T. J., B.S. (St. Bonaventure) Teacher, Rochester Shop School, Rochester, N.Y. *73 Martin St.*

CAIRNS, S. S., Ph.D. (Harvard) Instr., Lehigh Univ., Bethlehem, Pa. *525 W. Union Blvd.*
CAIRNS, Prof. W. D., Ph.D. (Göttingen) Oberlin Coll., Oberlin, Ohio. *33 Peters Hall.*
CALKINS, Prof. HELEN, A.M. (Columbia) Pennsylvania Coll. for Women, Pittsburgh, Pa.
CALLAWAY, Prof. THEODOSIA T., B.S. (Columbia) Stephens Coll., Columbia, Mo. *417 Hitt St.*
CAMERON, R. H., A.B. (Cornell) Instr., Cornell Univ., Ithaca, N. Y. *134 College Ave.*
CAMP, Prof. B. H., Ph.D. (Yale) Wesleyan Univ., Middletown, Conn. *110 Mt. Vernon St.*
CAMP, Prof. C. C., Ph.D. (Cornell) Univ. of Nebraska, Lincoln, Nebr. *Dept. of Math.*
CAMP, H. L., A.M. (Oklahoma) Instr., A. and M. Coll. of Texas, College Station, Tex. *P. O. Box 166, Faculty Exchange.*
CAMPBELL, Prof. A. D., Ph.D. (Cornell) Syracuse Univ., Syracuse, N. Y. *208 Westminster Ave.*
CAMPBELL, D. F., Ph.D. (Harvard) Actuary, 160 N. LaSalle St., Chicago, Ill.
CAMPBELL, G. A., Ph.D. (Harvard) Research Engineer, Amer. Tel. and Tel. Co., New York, N. Y. *Room 1654, 195 Broadway.*
CAMPBELL, G. C., M.S. (Iowa) Bell Telephone Labs., New York, N. Y. *463 West St.*
CAMPBELL, H. A., A.M. (Creighton) Teacher, Tech. High School, Omaha, Nebr. *32nd and Cuming.*
CAMPBELL, JESSIE R., A.B. (Syracuse) Instr., Hollywood Jr. Coll., Los Angeles, Calif. *5400 Brynhurst Ave.*
CAMPBELL, Prof. J. W., Ph.D. (Chicago) Univ. of Alberta, Edmonton South, Alta., Can.
CAMPBELL, Prof. W. B., A.M. (Cornell) Head of Dept., Judson Coll., Rangoon, Burma.
CANDY, Prof. A. L. Univ. of Nebraska, Lincoln, Nebr., *Station A.*
CANNING, JOSEPH, A.B. (Intermountain) Machinist, N. P. Ry. Co., Helena, Mont. *1813 Boulder Ave.*
CAPARO, Prof. J. A., Ph.D. (Notre Dame) Notre Dame Univ., Notre Dame, Ind. *1024 Leeper Ave., South Bend, Ind.*
CAPRON, Prof. PAUL, A.M. (Harvard) U. S. Naval Acad., Annapolis, Md. *203 Duke of Gloucester St.*

CAREY, Asso. Prof. E. F. A., M.S. (California) Univ. of Montana, Missoula, Mont.
CARIS, Pres. A. G., A.M. (Defiance) Defiance Coll., Defiance, Ohio.
CARIS, Asst. Prof. P. A., Ph.D. (Pennsylvania) Univ. of Pennsylvania, Philadelphia, Pa. *717 Runnymede Ave., Drexel Hill, Pa.*
CARLEN, MILDRED E., M.S. (Brown) Registrar, Grad. School, Brown Univ., Providence, R. I. *23 Exeter St.*
CARLSON, J. A., B.S. (Washington) Asso., Univ. of Washington, Seattle, Wash. *Dept. of Math.*
CARLSON, Asst. Prof. S. ELIZABETH, Ph.D. (Minnesota) Univ. of Minnesota, Minneapolis, Minn. *3020 14th Ave. S.*
CARMAN, M. D., Ph.D. (Illinois) Head of Dept., State Teachers Coll., Murray, Ky.
CARMICHAEL, Prof. F. L., A.M. (Princeton) Math. and Statistics, Univ. of Denver, Denver, Colo. *2230 Colorado Blvd.*
CARMICHAEL, Prof. R. D., Ph.D. (Princeton) Univ. of Illinois, Urbana, Ill. *207 W. Washington Blvd.*
CARPENTER, Prof. D. R., A.M. (Princeton) Roanoke Coll., Salem, Va.
CARR, Prof. E. L., A.M. (Chicago) Head of Dept., Union Univ., Jackson, Tenn. *109 Camden St.*
CARR, Prof. F. E., Ph.D. (Chicago) Math. and Astr., Oberlin Coll., Oberlin, Ohio. *On leave 1931–32, Mount Wilson Observatory.*
CARROLL, Asso. Prof. EVELYN T., A.M. (Wells) Wells Coll., Aurora, N. Y.
CARROLL, Asst. Prof. I. S., A.M. (Columbia) Syracuse Univ., Syracuse, N. Y. *511 Comstock Ave.*
CARRUTH, Prof. W. M., A.B. (Cornell) Hamilton Coll., Clinton, N. Y.
CARSCALLEN, Asso. Prof. G. E., A.M. (Illinois) Wabash Coll., Crawfordsville, Ind. *112 N. Barr St.*
CARTER, C. C. Attorney at Law, Bluffs, Ill. *R.D. No. 2.* Honorary Life Member.
CARUS, E. H., Ph.D. (Chicago) LaSalle, Ill.
CARUTHERS, R. W. E., B.S. (Miss. A. and M. Coll.) Engineer, International General Electric Co., Buenos Aires, Argentina. *Victoria 618.*
CARVER, Prof. W. B., Ph.D. (Johns Hopkins) Cornell Univ., Ithaca, N. Y. *White Hall.*
CARY, R. L., A.M. (Haverford) Prinz-Louis-Ferdinandstr. 5, Berlin N W 7, Germany.
CEDERBERG, Prof. W. E., Ph.D. (Wisconsin) Augustana Coll., Rock Island, Ill. *2542 22½ Ave.*
CELL, Asst. Prof. J. W., A.M. (Illinois) School of Eng., Southern Methodist Univ., Dallas, Tex.
CHACE, ARNOLD B., Sc.D. Chancellor, Brown Univ., Providence, R. I. *99 Power St.*
CHAMBERS, Prof. G. G., Ph.D. (Pennsylvania) Univ. of Pennsylvania, Philadelphia, Pa. *251 S. 38th St.*
CHANG, Prof. H. C., Ph.D. (Michigan) Central Univ., Nanking, China.
CHARLES, Prof. R. L., A.M. (Lehigh) Physics, Franklin and Marshall Coll., Lancaster, Pa. *510 Race Ave.*
CHAROSH, MANNIS, B.S. (C.C.N.Y.) Teacher, New Utrecht High School, Brooklyn, N. Y.
CHASE, L. R. Instr., Rogers High School, Newport, R. I. *Boulevard Ter.*
CHELLEVOLD, Asst. Prof. J. O., A.M. (Northwestern) St. Paul Luther Coll., St. Paul, Minn.
CHENEY, Prof. W. F., Jr., Ph.D. (Mass. Inst. of Tech.) Connecticut Agric. Coll., Storrs, Conn.
CHITTENDEN, Prof. E. W., Ph.D. (Chicago) Univ. of Iowa, Iowa City, Iowa. *1101 Kirkwood Ave.*
CHRISTIAN, R. S., A.B. (Westminster) Instr., Westminster Coll., Fulton, Mo.
CHRISTMAN, LAURA E., A.M. (Wisconsin) Teacher, Senn High School, Chicago, Ill. *1217 Elmdale Ave.*
CHURCH, Asso. Prof. E. F., C.E. (Syracuse) Photogrammetry, Univ. of Syracuse, Syracuse, N. Y. *Parish, N. Y.*
CHURCH, W. R., A.M. (Pennsylvania) Grad. Student, Yale Univ., New Haven, Conn. *463 Skiff St., Hamden, Conn.*
CLACK, Prof. R. W., A.M. (Grinnell) Math. and Astr., Alma Coll., Alma, Mich. *209 W. Downie St.*
CLAIRE, C. N., B.S. (Alfred) Junior Mathematician, U. S. Coast and Geodetic Survey, Washington, D. C.
CLARK, Asso. Prof. A. G., A.M. (Colorado) Colorado Agric. Coll., Fort Collins, Colo.
CLARK, R. F., A.B. (Williams) Chm., Math. Dept., DeWitt Clinton High School, New York, N. Y. *194 Christie Hts. St., Leonia, N. J.*
CLARKE, Prof. E. H., Ph.D. (Chicago) Math. and Astr., Hiram Coll., Hiram, Ohio. *Box 283.*
CLARKE, J. A., A.M. (Princeton) West Phila. High School for Boys, Philadelphia, Pa. *Devon, Pa.*

CLARKE, Sister M. BORGIA, A.M. (Catholic Univ.) Prof., Webster Coll., Webster Groves, Mo.
CLAWSON, Prof. J. W., M.A. (New Brunswick) Ursinus Coll., Collegeville, Pa.
CLAYTON, J. L., A.M. (Michigan) Instr., U. S. Naval Acad., Annapolis, Md. *20 Jefferson St.*
CLELAND, Prof. W. E., Ph.D. (Princeton) Geneva Coll., Beaver Falls, Pa. *North Hall.*
CLEMENTS, Prof. G. R., Ph.D. (Harvard) U. S. Naval Acad., Annapolis, Md. *7 Thompson St.*
COBB, Prof. H. E., A.M. (Wesleyan) Lewis Inst., Chicago, Ill.
COBLE, Prof. A. B., Ph.D. (Johns Hopkins) Univ. of Illinois, Urbana, Ill. *702 W. Washington Blvd.*
COE, Asst. Prof. C. J., Ph.D. (Harvard) Univ. of Michigan, Ann Arbor, Mich. *2022 Hill St.*
COFFIN, Prof. L. M., A.M. (Michigan) Coe Coll., Cedar Rapids, Iowa. *1027 Second Ave.*
COHEN, Prof. ABRAHAM, Ph.D. (Johns Hopkins) Johns Hopkins Univ., Baltimore, Md.
COHEN, Asst. Prof. L. W., Ph.D. (Michigan) Univ. of Kentucky, Lexington, Ky. *363 Aylesford Pl.*
COHEN, Asst. Prof. TERESA, Ph.D. (Johns Hopkins) Pennsylvania State Coll., State College, Pa. *512 W. Beaver Ave.*
COLAW, J. M., A.M. (Dickinson) Attorney at Law, Monterey, Va.
COLE, Prof. LENA R., A.M. (Missouri) Central Normal Coll., Danville, Ind.
COLEMAN, Prof. J. B., Ph.D. (California) Univ. of South Carolina, Columbia, S. C.
COLEMAN, Prof. R. H., A.B. (Charleston) Coll. of Charleston, Charleston, S. C.
COLLIER, MYRTIE, Ph. D. (Strasbourg) 320½ N. Alexandria Ave., Los Angeles, Calif.
COLLINS, O. C., M.A. (Oxford, England) Instr., Univ. of Nebraska, Lincoln, Nebr. *1920 S. 26th St.*
COLLITON, J. W., C.E., E.M. (Lafayette) Head of Dept., High School, Trenton, N. J. *223 Highland Ave.*
COLPITTS, Asso. Prof. JULIA T., Ph.D. (Cornell) Iowa State Coll., Ames, Iowa. *29 Cranford Apts.*
COLWELL, Prof. R. C., Ph.D. (Princeton) Physics, West Virginia Univ., Morgantown, W. Va. *332 Demain Ave.*
COLYER, Prof. E. E., A.M. (Kansas) State Teachers Coll., Hays, Kans. *408 W. 15th St.*
COMSTOCK, Prof. C. E., A.M. (Knox) Bradley Poly. Inst., Peoria, Ill. *203 Fredonia Ave.*
CONDIT, Prof. I. S., A.M. (Parsons) State Teachers Coll., Cedar Falls, Iowa. *115 E. 11th St.*
CONGDON, Asso. Prof. A. R., A.M. (Nebraska) Pedagogy of Math., Univ. of Nebraska, Lincoln, Nebr. *Station A.*
CONKLING, R. P., A.B. (Cornell) Head of Dept., Newark Tech. School and Central High School, Newark, N. J. *31 N. 10th St.*
CONKWRIGHT, N. B., Ph.D. (Illinois) Asso., Univ. of Iowa, Iowa City, Iowa. *120 Physics Bldg.*
CONLEE, R. H., A.B. (New Mexico) Supt. of Public Schools, Mountainair, N. Mex.
CONSTABLE, MARY LOUISE, A.M. (Pennsylvania) Teacher, Philadelphia High School for Girls, Philadelphia, Pa. *The Whittier, 140 N. 15th St.*
CONSTANTINE, JUNE F., B.S. (Minnesota) Statistician, Child Welfare Research Sta., Univ. of Iowa, Iowa City, Iowa.
CONWELL, G. M., Ph.D. (Princeton) Master in Math., St. Paul's School, Concord, N. H.
CONWELL, Prof. H. H., M.S. (Kansas) Beloit Coll., Beloit, Wis.
COOK, Asso. Prof. A. J., Ph.D. (Chicago) Univ. of Alberta, Edmonton, Alta., Can. *Dept. of Math.*
COOLEY, HOLLIS, A.M. (Middlebury) Instr., New York Univ., New York, N. Y. *32 Waverley Pl.*
COOLIDGE, Prof. J. L., Ph.D. (Bonn) Harvard Univ., Cambridge 38, Mass. *27 Fayerweather St.*
COOPER, Prof. A. E., Ph.D. (Chicago) Applied Math., Univ. of Texas, Austin, Tex. *Rice Ct., Rio Grande St.*
COOPER, ELIZABETH M., Ph.D. (Illinois) Prin., Buckingham School, Cambridge, Mass. *10 Buckingham St.*
COPE, Prof. T. F., Ph.D. (Chicago) Marietta Coll.. Marietta, Ohio.
COPELAND, Asso. Prof. LENNIE P., Ph.D. (Pennsylvania) Wellesley Coll., Wellesley, Mass. *14 Waban St.*
COPP, P. T., A.M. (Ohio State) Instr., Valparaiso Univ., Valparaiso, Ind. *812 Union St.*
CORAL, MAX, Ph.D. (Chicago) National Research Fellow, Harvard Univ., Cambridge, Mass. *23 Ware St.*
CORBIN, Prof. C. E., A.M. (Northwestern) Coll. of the Pacific, Stockton, Calif. *117 W. Euclid Ave.*
COREY, S. A. 1079 23rd St., Des Moines, Iowa.
CORLISS, J. J., Ph.D. (Michigan) Instr., Univ. of Michigan, Ann Arbor, Mich. *5 East Hall.*

CORONA, Sister MARIA, Ph.D. (Fordham) Teacher, Mount St. Joseph Coll., Mount St. Joseph, Ohio.
CORRAL Y ALEMAN, JOSÉ ISAAC, Ing. de Mines. Director de Montes y Mines, Republic of Cuba, Havana, Cuba. *Calzada esquina 13, Vedado.*
COSBY, Prof. BYRON, A.M. (Missouri) Math. and Bus. Admin., State Teachers Coll., Kirksville, Mo. *707 E. Normal Ave.*
COURT, Asso. Prof. N. A., D.Sc. (Ghent, Belgium) Univ. of Oklahoma, Norman, Okla.
COWLES, Prof. W. H. H., A.M. (Columbia) Head of Dept., Math. and English, Pratt Inst., Brooklyn, N. Y. *215 Ryerson St.*
COWLEY, Prof. ELIZABETH B., Ph.D. (Columbia) Vassar Coll., Poughkeepsie, N. Y. *On leave of absence, 913 Arch St., N.S., Pittsburgh, Pa.*
COX, Dean C. S., A.M. (Vanderbilt) Dean and Prof., Southern Coll., Lakeland, Fla.
COX, Asso. Prof. E. F., Ph.D. (Cornell) Howard Univ., Washington, D. C.
CRAIG, Asst. Prof. C. C., Ph.D. (Michigan) Univ. of Michigan, Ann Arbor, Mich. *3020 Angell Hall.*
CRAIG, Adj. Prof. H. V., Ph.D. (Wisconsin) Applied Math., Univ. of Texas, Austin, Tex. *3208 Grandview Ave.*
CRAMLET, Asst. Prof. C. M., Ph.D. (Washington) Univ. of Washington, Seattle, Wash. *Phil. Hall.*
CRANE, Asso. Prof. RUFUS, A.M. (Ohio State) Math. and Eng., Ohio Wesleyan Univ., Delaware, Ohio. *39 Montrose Ave.*
CRATHORNE, Asso. Prof. A. R., Ph.D. (Göttingen) Univ. of Illinois, Urbana, Ill. *802 Pennsylvania Ave.*
CRAWLEY, Prof. E. S., Ph.D. (Pennsylvania) Univ. of Pennsylvania, Philadelphia, Pa. *College Hall.*
CRENSHAW, Prof. B. H., M.E. (Alabama Poly. Inst.) Alabama Poly. Inst., Auburn, Ala.
CROCKETT, Prof. C. W., C.E. (Rensselaer) Math. and Astr., Rensselaer Poly. Inst., Troy, N. Y. *221 Stow Ave.*
CROMWELL, J. W., Jr., A.M. (Dartmouth) Certified Publ. Accountant; Controller, Howard Univ., Washington, D. C. *1815-13th St. N.W.*
CROOM, Pres. A. S. Oklahoma Christian Coll., Cordell, Okla.
CROSS, Asst. Prof. SAVANNAH L., A.M. (Michigan) State Teachers Coll., Nacogdoches, Tex. *On leave 1931–32, Stanford Univ., Stanford University, Calif.*
CROWE, Asso. Prof. S. E., A.M. (Michigan) Michigan State Coll., East Lansing, Mich.
CRUDELI, Prof. UMBERTO, Dr. in mat. (Rome) Director, Math. Inst., Univ. of Cagliari, Sardinia, Italy.
CRUM, Prof. W. L., Ph.D. (Yale) Economic Statistics, Harvard Univ., Cambridge, Mass.
CULMER, ORPHA A., A.M. (Michigan) State Normal School, Florence, Ala. *217 Oneal Ave.*
CUMMING, Asso. Prof. FORREST, A.M. (Georgia) Univ. of Georgia, Athens, Ga. *Box 786.*
CUMMINGS, Prof. LOUISE D., Ph.D. Vassar Coll., Poughkeepsie, N. Y.
CUNHA, Prof. PEDRO JOSÉ DA. Math. Analysis, Faculty of Sc., Lisbon Univ., and Rector of the Univ., Lisbon, Portugal. *Rua de S. Bento, No. 706.*
CURRIER, Asso. Prof. C. H., A.M. (Brown) Brown Univ., Providence, R. I.
CURRY, Asst. Prof. H. B., Ph.D. (Göttingen) Pennsylvania State Coll., State College, Pa. *805 W. Beaver Ave. On leave 1931–32, Univ. of Chicago.*
CURTIS, Prof. H. B., Ph.D. (Cornell) Lake Forest Coll., Lake Forest, Ill. *College Hall.*
CURTISS, Prof. D. R., Ph.D. (Harvard) Northwestern Univ., Evanston, Ill. *2023 Sherman Ave.*
CUTLER, E. H., Ph.D. (Harvard) Instr., Lehigh Univ., Bethlehem, Pa. *Dept. of Math.*
CUTTING, L. H., A.M. (Missouri) Teacher, Westport High School, Kansas City, Mo. *406 E. 43rd St.*

DADOURIAN, Prof. H. M., Ph.D. (Yale) Trinity Coll., Hartford, Conn. *125 Vernon St.*
DAHLENE, Prof. OSCAR, M.S. (Kansas) Eng. and Math., Univ. of Alabama, University, Ala.
DALAKER, Prof. H. H., Ph.D. (Cornell) Math. and Mech., Coll. of Eng. and Arch., Univ. of Minnesota, Minneapolis, Minn. *523 Walnut St. S.E.*
DALE, Asst. Prof. JULIA, Ph.D. (Cornell) Duke Univ., Durham, N. C.
DALTON, Prof. J. P., D.Sc. (St. Andrews; Cape) Univ. of the Witwatersrand, Johannesburg, S. Africa, *P. O. Box 1176.*
DAME, Prof. MABELLE C., Ph.D. (Chicago) 50 Cedar St., Amesbury, Mass.
DANCER, Asst. Prof. C. W., A.M. (Ohio State) Univ. of the City of Toledo, Toledo, Ohio. *1929 Ottawa Dr.*
DANIELLS, Asst. Prof. MARIAN E., M.S. (Iowa State) Iowa State Coll., Ames, Iowa.
DAPPERT, J. W. Civil Engineer, Taylorville, Ill. *Lock Box 141.*
DARKOW, Asst. Prof. MARGUERITE D., Ph.D. (Chicago) Hunter Coll., New York, N. Y.
DARLING, F. W., A.B. (Cornell) Asso. Mathematician, U. S. Coast and Geodetic Survey, Washington, D. C.

DARNELL, ALBERTUS, Ph.B. (Michigan) Asst. Dean, Coll. of the City of Detroit, Detroit, Mich. *1216 Edison Ave.*
DARRAGH, MARGARET L., A.B. (Hanover Coll.) Teacher, Roosevelt High School, East Chicago, Ind. *4144 Northcote Ave.*
DAUENHAUER, HELEN A., A.B. (Hunter) Tutor, Hunter Coll., New York, N. Y. *217 E. 176 St.*
DAUGHERTY, R. D., M.S. (Iowa) Instr., State Agric. Coll., Manhattan, Kans.
DAUS, Asso. Prof. P. H., Ph.D. (California) Univ. of California at Los Angeles, Los Angeles, Calif. *405 N. Hilgard Ave.*
DAVIS, C. H. 95 Jefferson St., Hartford, Conn.
DAVIS, Prof. D. R., Ph.D. (Chicago) State Teachers Coll., Montclair, N. J.
DAVIS, Asst. Prof. H. A., Ph.D. (Cornell) West Virginia Univ., Morgantown, W. Va. *307 Duquesne Ave.*
DAVIS, Asso. Prof. H. T., Ph.D. (Wisconsin) Indiana Univ., Bloomington, Ind. *712 E. Second St.*
DAVIS, Asso. Prof. J. E., A.M. (Wisconsin) Drexel Inst., Philadelphia, Pa.
DAVIS, Prof. J. M., A.M. (Kentucky) Univ. of Kentucky, Lexington, Ky. *340 Madison Pl.*
DAVIS, J. W., A.M. (Yale) Teacher, High School, Boston, Mass. *17 Wrentham St., Dorchester, Mass.*
DAVIS, W. M., M.S. (Iowa) Instr., Armour Inst. of Tech., Chicago, Ill. *3300 Federal St.*
DAWSON, Prof. J. D., M.S. (Ohio State) Antioch Coll., Yellow Springs, Ohio.
DAY, EDNA L., A.M. (Northwestern) Britt, Iowa.
DEAN, ALICE C., A.M. (Rice) Fellow, Rice Inst., Houston, Tex.
DEAN, MILDRED W. (Mrs. C. E.), Ph.D. (Johns Hopkins) 3908-213 St., Bayside, L. I., N. Y.
DEARMAN, Prof. D. S., A.M. (Vanderbilt) State Teachers Coll., Hattiesburg, Miss.
DECHERD, Adj. Prof. MARY E., A.M. (Texas) Pure Math., Univ. of Texas, Austin, Tex. *2313 Nueces St.*
DECKER, Prof. F. F., Ph.D. (Syracuse) Syracuse Univ., Syracuse, N. Y. *312 Marshall St.*
DECLEENE, Rev. L. A.V., Ph.D. (Catholic Univ.) Prof., St. Norbert Coll., West DePere, Wis.
DECOU, Prof. E. E., M.S. (Chicago) Univ. of Oregon, Eugene, Ore. *929 Hilyard St.*
DEDERICK, L. S., Ph.D. (Harvard) Mathematician, Aberdeen Proving Ground, Md.
DE LA GARZA, E. Box 304, Brownsville, Tex.
DELONG, Prof. I. M., A.M. (Simpson) Emeritus, Univ. of Colorado, Boulder, Colo. *517 Pine St.*
DELURY, Prof. A. T., M.A. (Toronto) Univ. of Toronto, Toronto, Ont., Can.
DEMING, Prof. R. M., B.S. (Iowa State) Upper Iowa Univ., Fayette, Iowa.
DENNISON, C. H. Grad. Mass. Inst. of Tech. Chemist, Amer. Rubber Co., Cambridge, Mass. *183 Norfolk St., Wollaston, Mass.*
DENNY, Prof. A. K., M.S. (Lincoln) Prof. and Registrar, Lincoln Coll., Lincoln, Ill. *221 Oglesby Ave.*
DENTON, Asst. Prof. W. W., Ph.D. (Illinois) Univ. of Michigan, Ann Arbor, Mich. *1014 Cornwell Pl.*
DEUTSCH, RALPH, A.M. (Columbia) Teacher, New Utrecht High School, Brooklyn, N. Y. *654 Warwick St.*
DICE, ELIZABETH S., A.M. (Texas) Teacher, High School, Dallas, Tex.
DICKINSON, Prof. C. N. Hollins College, Hollins, Va.
DICKSON, Prof. L. E., Ph.D. (Chicago) Univ. of Chicago, Chicago, Ill., *5535 University Ave.*
DICKSTEIN, Prof. S., Ph.D. Math. and Hist., Univ. of Warsaw, Warsaw, Poland. *Marszalkowska St. 117.*
DILLINGHAM, Prof. ALEXANDER. U. S. Naval Acad., Annapolis, Md.
DIMICK, Prof. C. E., A.M. (Pennsylvania) U. S. Coast Guard Acad., New London, Conn.
DINES, Dean L. L., Ph.D. (Chicago) Univ. of Saskatchewan, Saskatoon, Sask., Can.
DINWIDDIE, Pres. A. B., Ph.D. (Virginia) Pres., and Prof. of Math., Tulane Univ., New Orleans, La. *Station 20.*
DOAK, Prof. ELEANOR C., Ph.B. (Chicago) Mount Holyoke Coll., South Hadley, Mass.
DOAN, Asst. Prof. C. S., A.M. Purdue Univ., W. LaFayette, Ind. *415 Russell St.*
DOBBIN, Sister MARIOLA, A.M. (Wisconsin) Rosary Coll., River Forest, Ill.
DO BELL, Asst. Prof. H. A., Ph.D. (Cornell) State Coll. for Teachers, Albany, N. Y.
DODD, Prof. E. L., Ph.D. (Yale) Univ. of Texas, Austin, Tex. *3012 West Ave.*
DOERMANN, Asst. Prof. F. W., Ph.D. (Vienna) Math. Physics, New York Univ., New York, N. Y. *University Hts.*
DONAGHHO, Prof. J. S., A.M. (Marietta) Univ. of Hawaii, Honolulu, T. H. *961 Alewa Dr.*
DONAHUE, Asso. Prof. J. E., A.M. (Harvard) Univ. of Vermont, Burlington, Vt. *Essex Junction, Vt.*
DORROH, J. L., Ph.D. (Texas) National Research Fellow, Princeton Univ., Princeton, N. J. *I-1 Prospect Apt.*

DORWART, H. L., Ph.D. (Yale) Instr., Williams Coll., Williamstown, Mass. *Faculty Club.*
DOSTAL, Asst. Prof. B. F., A.M. (Indiana) Univ. of Florida, Gainesville, Fla. *Engineering Bldg.*
DOTTERER, Prof. J. E., A.M. (Illinois) Head of Dept., Manchester Coll., North Manchester, Ind.
DOUGHERTY, LUCY T., A.M. (Kansas) Instr., Jr. Coll., Kansas City, Kans. *Gould Hotel.*
DOUGHTY, ANNIE W., A.M. (Radcliffe) Teacher, Dana Hall School, Wellesley, Mass.
DOUGLAS, J. L., A.M. (Davidson) Davidson Coll., Davidson, N. C.
DOUGLASS, Prof. R. D., Ph.D. (Mass. Inst. of Tech.) Mass. Inst. of Tech., Cambridge, Mass. *76 Drew Rd., Belmont, Mass.*
DOWNING, Prof. H. H., Ph.D. (Chicago) Univ. of Kentucky, Lexington, Ky. *138 State St.*
DRESDEN, Prof. ARNOLD, Ph.D. (Chicago) Swarthmore Coll., Swarthmore, Pa. *606 Elm Ave.*
DRESSEL, F. G., M.S. (Michigan) Instr., Duke Univ., Durham, N. C. *Box 4393.*
DREW, J. W., A.M. (Cornell) Head of Dept., Storer Coll., Harpers Ferry, W. Va. *Box 202.*
DRIVER, D. D., A.M. (Nebraska) Instr., Hesston Coll., Hesston, Kans.
DRUMMOND, Asst. Prof. G. B., M.S. (U. S. Milit. Acad.) Oklahoma A. and M. Coll., Stillwater, Okla. *Box 161.*
DUBE, Prof. L. H., Ph.D. (Gregorian Univ., Rome) Higher Math., Ottawa Univ., Ottawa, Ont., Can.
DUERKSEN, J. A., A.B. (Bethel) Asst. Mathematician, U. S. Coast and Geodetic Survey, Washington, D. C. *3134 Monroe St. N.E.*
DUNCAN, BERTHA K., Ph.D. (Texas) Instr., Phil. and Psych., Texas State Coll. for Women, Denton, Tex. *Box 604, C.I.A. Sta.*
DUNFORD, NELSON, Ph.B. (Chicago) Grad. Student, Univ. of Chicago, Chicago, Ill. *60 Snell Hall.*
D'UNGER, V. C., A.M. (Little Rock) Lincoln Natl. Life Ins. Co., Fort Wayne, Ind.
DUNKEL, Prof. OTTO, Ph.D. (Harvard) Washington Univ., St. Louis, Mo.
DUNLAP, L. T., B.S. (Marquette) Instr., Pennsylvania State Coll., State College, Pa. *Dept. of Math.*
DU PASQUIER, Prof. L. G., Ph.D. (Zurich) Head of Dept., Univ. of Neuchâtel, Neuchâtel, Switzerland. *Beaux-Arts 4.*
DURELL, FLETCHER, Ph.D. (Princeton) Emeritus, formerly Head of Dept., Lawrenceville School, Lawrenceville, N. J. *Belleplain, N. J.*
DUREN, Asst. Prof. W. L., Jr., Ph.D. (Chicago) Tulane Univ., New Orleans, La.
DURFEE, Prof. W. H., Ph.D. (Cornell) Hobart Coll., Geneva, N. Y. *403 Pulteney St.*
DURFEE, Prof. W. P., Ph.D. (Johns Hopkins) Hobart Coll., Geneva, N. Y. *639 Main St.*
DUSTHEIMER, Prof. O. L., Ph.D. (Michigan) Astr. and Math., Baldwin-Wallace Coll., Berea, Ohio. *272 Beech St.*
DUVAL, Asso. Prof. E. P. R., A.M. (Harvard) Univ. of Oklahoma, Norman, Okla. *Faculty Exchange.*
DWYER, Asso. Prof. P. S., A.M. (Penna. State) Antioch Coll., Yellow Springs, Ohio. *Box 94.*
DYE, L. A., Ph.D. (Cornell) Instr., Cornell Univ., Ithaca, N. Y. *White Hall 8.*

EAGLES, Prof. T. R., A.M. (North Carolina) Howard Coll., Birmingham, Ala. *3016 Second Ave. S.*
EARHART, FRANC C., A.M. (Wisconsin) Lenox Coll., Hopkinton, Iowa.
EARL, Asso. Prof. J. M., Ph.D. (Minnesota) Univ. of Omaha, Omaha, Nebr. *3160 Dodge St.*
EARLE, Prof. M. D., A.M. (Furman) Furman Univ., Greenville, S. C.
ECHOLS, Col. C. P. Prof., U. S. Milit. Acad., West Point, N. Y.
ECHOLS, Prof. W. H., C.E. (Virginia) Univ. of Virginia, University, Va.
EDINGTON, Prof. W. E., Ph.D. (Illinois) Head of Dept., DePauw Univ., Greencastle, Ind.
EDMONDSON, AUBREY, B.S. in C.E. (Miss. A. and M. Coll.) Instr., Miss. A. and M. Coll., Starkville, Miss. *Box 2.*
EDMONDSON, Prof. T. W., Ph.D. (Clark) New York Univ., New York, N. Y. *University Hts.*
EDMONSON, Asst. Prof. NAT, Jr., Ph.D. (Rice) Texas Tech. Coll., Lubbock, Tex. *Box 124.*
EDMONSTON, J. H., A.B. (George Washington) 1441 Fairmont St. N.W., Washington, D. C.
EDWARDS, Asso. Prof. P. D., Ph.D. (Indiana) Ball State Teachers Coll., Muncie, Ind. *713 W. North St.*
EELLS, Prof. W. C., Ph.D. (Stanford) Educ., Stanford University, Calif. *735 Dolores St.*
EIDE, MARGARET CHAPMAN (Mrs. R. B.), A.M. (Wisconsin) State Teachers Coll., River Falls, Wis. *308 S. Second St.*
EIESLAND, Prof. J. A., Ph.D. (Johns Hopkins) West Virginia Univ., Morgantown, W. Va.
EISELE, CAROLYN, A.M. (Hunter) Instr., Hunter Coll., New York, N. Y. *650 E. 231 St.*
EISENHART, Dean L. P., Ph.D. (Johns Hopkins) Princeton Univ., Princeton, N. J. *73 Nassau St.*

ELDER, J. D., Ph.D. (Calif. Inst. of Tech.) Instr., Univ. of Michigan, Ann Arbor, Mich. *Dept. of Math.*
ELLIOTT, Prof. W. W., Ph.D. (Cornell) Duke Univ., Durham, N. C. *Box 533.*
ELSTON, J. S., A.B. (Cornell) Asst. Actuary, Travelers Ins. Co., Hartford, Conn.
EMCH, Prof. ARNOLD, Ph.D. (Kansas) Univ. of Illinois, Urbana, Ill. *1002 S. Orchard St.*
EMMONS, Prof. C. W., A.M. (Illinois) Simpson Coll., Indianola, Iowa. *1009 N. B St.*
EMMONS, Prof. L. C., A.M. (Harvard) Mathl. Statistics, Michigan State Coll., East Lansing, Mich.
ENGLISH, HARRY, A.B. (Johns Hopkins), LL.M. (Columbia) Head of Dept., Washington High Schools, Washington, D. C.
ENRIQUES, Prof. FEDERIGO. Univ. of Rome, Rome, Italy. *Via Sardegna 50.*
ENTZ, G. G., B.S. (Columbia) 1352 Poinsettia Pl., Hollywood, Calif.
ERICKSON, Asst. Prof. E. E., M.S. (Iowa) Miami Univ., Oxford, Ohio.
ERIKSON, Asst. Prof. C. M., Ph.D. (Michigan) Michigan State Normal Coll., Ypsilanti, Mich. *504 N. Huron St.*
ERNSBERGER, IVA B., A.M. (Nebraska) Teacher, Fullerton High School and Jr. Coll., Fullerton, Calif.
ERWIN, GRACE, A.B. (Nebraska) Grad. Student, Univ. of Minnesota, Minneapolis, Minn. *316-16th Ave. S.E.*
ESCOTT, E. B., M.S. (Chicago) Actuary and Accountant, 1019 S. East Ave., Oak Park, Ill.
ESHLEMAN, J. D., Ph.D. (Chicago) Paradise, Pa.
ESTY, Dean T. C., A.M. (Amherst) Amherst Coll., Amherst, Mass.
ETTINGER, W. J., B.S. in M.E. (Lewis Inst.) Research Engineer, Edison Electric Appliance Co., Chicago, Ill. *5600 W. Taylor St.*
ETTLINGER, Prof. H. J., Ph.D. (Harvard) Pure Math., Univ. of Texas, Austin, Tex. *3110 Harris Park Ave.*
EVANS, Prof. G. C., Ph.D. (Harvard) Pure Math., Rice Inst., Houston, Tex.
EVANS, G. W., A.B. (Harvard) Charlestown High School, 107 Ocean St., Lynn, Mass. *Retired.*
EVANS, Prof. H. B., Ph.D. (Pennsylvania) Univ. of Pennsylvania, Philadelphia, Pa. *College Hall.*
EVANS, Asst. Prof. H. P., Ph.D. (Wisconsin) Univ. of Wisconsin, Madison, Wis. *North Hall.*
EVANS, P. H. Vice-Pres., and Actuary, Northwestern Mut. Life Ins. Co., Milwaukee, Wis. *720 E. Wisconsin Ave.*
EVERETT, Prof. H. S., Ph.D. (Chicago) Extension Prof., Univ. of Chicago, Chicago, Ill. *5545 Woodlawn Ave.*
EVERETT, Prof. J. P., Ph.D. (Columbia) Chm. Dept. of Math., State Teachers Coll., Kalamazoo, Mich. *907 W. South St.*
EVERETT, Asso. Prof. J. R., A.M. (Wisconsin) Colorado School of Mines, Golden, Colo. *1700 Washington St.*
EVERS, Prof. CORNELIUS, M.S. (Michigan State) Central Univ. of Iowa, Pella, Iowa.
EWIN, MARY, A.M. (George Washington) Teacher, Eastern High School, Washington, D. C. *3629 Tenth St. N. W.*
EWING, W. M., A.M. (Rice) Physics, Lehigh Univ., Bethlehem, Pa. *Dept. of Physics.*

FAHNESTOCK, SARAH. Head of Dept., Marymount Coll., Salina, Kans.
FAIRCHILD, Prof. J. T., A.M., C.E. (Ohio Northern), Ph.M. (Carnegie Inst.) Ohio Northern Univ., Ada, Ohio.
FARNUM, FAY, Ph.D. (Cornell) Instr., Washington Square Coll., New York Univ., New York, N. Y. *Washington Sq.*
FAULKNER, Prof. DONALD, A.B. (Stetson) J. B. Stetson Univ., DeLand, Fla.
FEDERICO, P. J., A.M. (George Washington) Asso. Examiner, U. S. Patent Office, Washington, D. C. *1451 Park Rd. N.W.*
FEEMSTER, Prof. H. C., A.M. (Nebraska) York Coll., York, Nebr.
FEENBERG, EUGENE. Asst., Physics, Univ. of Texas, Austin, Tex. *Dept. of Physics.*
FEHN, Asso. Prof. A. R., Ph.B. (Baldwin-Wallace) Centre Coll., Danville, Ky. *421 W. Lexington Ave.*
FEHR, Prof. HENRI, D. es. S. (Geneva) Univ. of Geneva, Geneva, Switzerland. *110 Florissant St.*
FELD, J. M., A.B., Chem.E. (Columbia) Instr., Columbia Coll., New York, N. Y. *Furnald Hall, Columbia Univ.*
FELDER, VIRGINIA I., M.S. (Tulane) Head of Dept., Copiah-Lincoln Jr. Coll., Wesson, Miss.
FELTGES, EDNA M., A.M. (Wisconsin) 2213 Asbury Ave., Evanston, Ill.
FENNER, BEATRICE A., A.M. (Stanford) Margaret Baylor Inn, Santa Barbara, Calif.
FERGUSON, Prof. C. E., A.M. (Missouri) Stephen F. Austin State Teachers Coll., Nacogdoches, Tex.

FERRY, Pres. F. C., Ph.D. (Clark) Hamilton Coll., Clinton, N. Y.
FIELD, FLORENCE E., A.M. (Michigan) Teacher, High School and Jr. Coll., Jackson, Mich. *511 W. Michigan Ave.*
FIELD, Prof. FLOYD, A.M. (Harvard) Dean of Men, Georgia School of Tech., Atlanta, Ga. *Route 1, Decatur, Ga.*
FIELD, Prof. PETER, Ph.D. (Cornell) Univ. of Michigan, Ann Arbor, Mich. *904 Olivia Ave.*
FIELD, S. E., A.M. (Michigan) Instr., Univ. of Michigan, Ann Arbor, Mich. *Edgewood Hills, R.F.D. 3.*
FIELDS, Prof. J. C., Ph.D. (Johns Hopkins) Univ. of Toronto, Toronto, Ont., Can.
FINDLAY, Prof. WILLIAM, Ph.D. (Chicago) McMaster Univ., Hamilton, Ont., Can. *131 Chedoke Ave.*
FINKEL, Prof. B. F., Ph.D. (Pennsylvania) Math. and Physics, Drury Coll., Springfield, Mo. Honorary Life Member. *1227 Clay St.*
FINLAY, A. E., A.M. (Peabody) Instr., A. and M. Coll., of Texas, College Station, Tex. *Faculty Exchange.*
FINLEY, Prof. G. W., M.S. (Kansas State) State Teachers Coll., Greeley, Colo. *1933 Ninth Ave.*
FISANICK, GEORGE, A.B. (Penna. State) Grad. Student, Univ. of Michigan, Ann Arbor, Mich. *Box 584, Barnesboro, Pa.*
FISCHER, C. H., M.S. (Iowa) Grad. Asst., Univ. of Iowa, Iowa City Iowa. *Dept. of Math.*
FISHER, Prof. IRVING, Ph.D. (Yale) Pol. Econ., Yale Univ., New Haven, Conn. *460 Prospect St.*
FISK, Dean N. C., Sc.D. (Michigan) Itasca Jr. Coll., Coleraine, Minn.
FISKE, Prof. T. S., Ph.D. (Columbia) Columbia Univ., New York, N. Y.
FITCH, ANNIE L. M. (Mrs. Edward), Ph.D. (Cornell) Clinton, N. Y.
FITE, Prof. W. B., Ph.D. (Cornell) Columbia Univ., New York, N. Y. *Hamilton Hall.*
FITTERER, Prof. J. C., C.E. (Colorado) Head of Dept., Colorado School of Mines, Golden, Colo.
FLAGG, Asst. Prof. ELINOR B., M.S. (Illinois) Illinois State Normal Univ., Normal, Ill.
FLANDERS, Asst. Prof. D. A., Ph.D. (Pennsylvania) New York Univ., New York, N. Y. *40 Morningside Ave.*
FLANDERS, Asst. Prof. R. L., B.S. (Norwich) Civ. Eng., Oklahoma A. and M. Coll., Stillwater, Okla. *908 W. Fourth St.*
FLEET, Prof. R. R., Ph.D. (Heidelberg) Math. and Astr., Central Coll., Fayette, Mo.
FLEISHER, Asst. Prof. EDWARD, M.S. (New York Univ.) Brooklyn Coll., Brooklyn, N. Y. *1068 Park Pl.*
FLEMING, Asst. Prof. ANNIE W., A.M. (California) Iowa State Coll., Ames, Iowa. *719 Douglas Ave.*
FLOOD, M. M., A.M. (Nebraska) Asst., Princeton Univ., Princeton, N. J.
FLYNN, B. D., A.M. Secy. and Actuary, Travelers Ins. Co., Hartford, Conn. *700 Main St.*
FLYNN, J. D., A.M. (Tufts) Statistician, Goodwin-Beach & Co., Investment Brokers, Hartford, Conn. *93 N. Beacon St.*
FOARD, Prof. C. W., Ph.D. (Iowa) Math. and Physics, Youngstown Coll., Youngstown, Ohio.
FOBERG, J. A., B.S. (Illinois) State Teachers Coll., California, Pa. *Dept. of Math.*
FOCKE, Dean T. M., Ph.D. (Göttingen) Kerr Prof. of Math., Case School of Appl. Sc., Cleveland, Ohio.
FOLK, PAULINE F., A.M. (Colorado) 519 N. Tejon St., Colorado Springs, Colo.
FOLLEY, Asst. Prof. K. W., Ph.D. (Toronto) Coll. of the City of Detroit, Detroit, Mich.
FORAKER, Prof. F. A., M.S. (Ohio Northern) Univ. of Pittsburgh, Pittsburgh, Pa. *1313 Macon Ave., Swissvale, Pa.*
FORD, Asst. Prof. L. R., Ph.D. (Harvard) Rice Inst., Houston, Tex.
FORD, Prof. W. B., Ph.D. (Harvard) Univ. of Michigan, Ann Arbor, Mich. *904 Forest Ave.*
FORSYTH, Asst. Prof. C. H., Ph.D. (Michigan) Dartmouth Coll., Hanover, N. H.
FORT, Prof. TOMLINSON, Ph.D. (Harvard) Analysis, Lehigh Univ., Bethlehem, Pa.
FOSTER, R. M., B.S. (Harvard) Dept. of Devel. and Research, Amer. Tel. and Tel. Co., New York, N. Y. *195 Broadway.*
FOX, A. H., A.M. (Harvard) Instr., Yale Univ., New Haven, Conn. *115 Pendleton St.*
FRANK, D. H., B.S. (C.C.N.Y.) Teacher, George Washington High School, New York, N. Y. *3135 Decatur Ave., Bronx, N. Y.*
FRANKEL, E. T., B.S. (C.C.N.Y.) Statistician, Natl. Indus. Conference Bd., Inc., New York, N. Y. *295 Convent Ave., Apt. 63.*
FRANKENBUSH, BERTHA E., A.M. (Tulane) Teacher, High School, New Orleans, La. *4502 Prytania St., Apt. B.*
FRANKLIN, Asso. Prof. PHILIP, Ph.D. (Princeton) Mass. Inst. of Tech., Cambridge, Mass.
FREAS, ELIZABETH, A.B. (Lake Erie) Overlook Sanitarium, New Wilmington, Pa.

FRÉCHET, Prof. MAURICE. Prof. à la Faculté des Sciences, Institut Henri Poincaré, Paris, France. *1 Rue Pierre Curie, Paris (5).*
FRECHEVILLE, GEORGE, M.A. (Oxford; Cambridge) Agric. Econ. Research Inst., Univ. of Oxford, Oxford, England. *Parks Road.*
FREMD, Dean LYDIA K., A.M. (Kentucky) Lees Coll., Jackson, Ky. *Eminence, Ky.*
FRINK, Asso. Prof. ORRIN, Jr., Ph.D. (Columbia) Pennsylvania State Coll., State College, Pa.
FRUMVELLER, Prof. A. F. Univ. of Detroit, Detroit, Mich. *651 E. Jefferson Ave.*
FRY, T. C., Ph.D. (Wisconsin) Bell Telephone Labs., New York, N. Y. *463 West St.*
FUBINI, Dr. GUIDO. Prof. of Analysis, Univ. and École Polytech., Turin, Italy. *Via Pietro Micca 12, Turin (108).*
FULLER, GORDON, A.M. (Michigan) Instr., Univ. of New Mexico, Albuquerque, N. Mex. *900 E. Silver Ave.*
FULLER, K. G., A.M. (Nebraska) Instr., Long Island Univ., Brooklyn, N. Y.
FULMER, Asso. Prof. H. K., A.M. (Columbia) Georgia School of Tech., Atlanta, Ga.
FUNK, Asst. Prof. J. C., A.M. (Columbia) Jr. Coll., Santa Maria, Calif. *910 S. McClelland St.*
FUNKHOUSER, H. G., A.M. (Columbia) Instr., Columbia Univ., New York, N. Y. *2940 Broadway.*

GABA, Prof. M. G., Ph.D. (Chicago) Univ. of Nebraska, Lincoln, Nebr.
GAFAFER, W. M., Sc.D. (Johns Hopkins) Research Asso., Johns Hopkins Univ., Baltimore, Md. *185 Glenwood Ave., Leonia, N. J.*
GAGE, Asst. Prof. W. H., M.A. (Univ. of B. C.) Victoria Coll., Victoria, B. C., Can. *Dept. of Math.*
GAINES, Prof. R. E., A.M. (Furman) Univ. of Richmond, Richmond, Va.
GALE, Prof. A. S., Ph.D. (Yale) Univ. of Rochester, Rochester, N. Y. *11 Thayer St.*
GARABEDIAN, Asso. Prof. C. A., Ph.D. (Harvard) St. Stephen's Coll., Columbia Univ., Annandale-on-Hudson, N. Y.
GARABEDIAN, H. A., B.S. (Tufts) Mathematician, John Hancock Mut. Life Ins. Co., Boston, Mass. *197 Clarendon St.*
GARABEDIAN, H. L., Ph.D. (Princeton) Instr., Northwestern Univ., Evanston, Ill. *2125 Ridge Ave.*
GARDINER, J. A., A.M. (Pennsylvania) Teacher, Howard High School, Wilmington, Del. *1305 Tatnall St.*
GARNETT, W. W., A.M. (Kentucky) Actuarial Dept., Central Life Assur. Co., Des Moines, Iowa. *613 Central Y.M.C.A.*
GARRETSON, Asso. Prof. W. V. N., Ph.D. (Michigan) Oklahoma A. and M. Coll., Stillwater, Okla. *623 Hester St.*
GARRETT, Prof. W. H., A.M. (Illinois Coll.) Vice-Pres., and Prof. of Math. and Astr., Baker Univ., Baldwin, Kans.
GARVER, Asso. Prof. RAYMOND, Ph.D. (Chicago) Univ. of California at Los Angeles, Los Angeles, Calif.
GAULT, Asso. Prof. A. E., M.S. (Chicago) Bradley Poly. Inst., Peoria, Ill.
GAVER, H. H., A.M. (Virginia) Headmaster, Black-Foxe Milit. Inst., Los Angeles, Calif. *637 N. Wilcox Ave.*
GAY, Asst. Prof. H. J., A.M. (Clark) Worcester Poly. Inst., Worcester, Mass. *7 Belvidere Ave.*
GAYLORD, H. D., A.M. (Harvard) Asst. Headmaster, Browne and Nichols School, Cambridge, Mass. *Hotel Commander.*
GAYLORD, Asst. Prof. LESLIE J., M.S. (Chicago) Agnes Scott Coll., Decatur, Ga.
GECKELER, Prof. O. T., A.B. (Indiana) Head of Dept., Carnegie Inst. of Tech., Pittsburgh, Pa.
GEHMAN, Prof. H. M., Ph.D. (Pennsylvania) Univ. of Buffalo, Buffalo, N. Y. *163 Winspear Ave.*
GENTRY, F. C., A.M. (Oklahoma) Instr., Tulane Univ., New Orleans, La.
GENTZLER, W. E., A.M. (Columbia) Asst., Columbia Univ., New York, N. Y. *2940 Broadway.*
GEORGES, J. S., Ph.D. (Chicago) Crane Jr. Coll., Chicago, Ill. *2245 Jackson Blvd.*
GERST, Rev. F. J., Ph.D. (Johns Hopkins) Dir. Dept. of Math., Loyola Univ., Chicago, Ill.
GETCHELL, B. C., A.M. (Harvard) Grad. Student, Univ. of Michigan, Ann Arbor, Mich. *432 Thompson St.*
GHORMLEY, Asst. Prof. L. O., A.M. (Chicago) Univ. of Tennessee, Knoxville, Tenn.
GIBBENS, Asst. Prof. GLADYS E. C., Ph.D. (Chicago) Univ. of Minnesota, Minneapolis, Minn. *122 Folwell Hall.*
GIBSON, Prof. J. L., Ph.D. (Vienna) Univ. of Utah, Salt Lake City, Utah.

GILL, Asst. Prof. B. P., Ph.D. (Columbia) Coll. of the City of New York, New York, N. Y. *302 Convent Ave.*

GILLESPIE, Prof. D. C., Ph.D. (Göttingen) Cornell Univ., Ithaca, N. Y. *Cayuga Hts.*

GILLESPIE, Prof. WILLIAM, Ph.D. (Chicago) Princeton Univ., Princeton, N. J. *Graduate College.*

GILLEY, C. A., A.B. (Texas) Sul Ross State Teachers Coll., Alpine, Tex.

GILMAN, Asst. Prof. R. E., Ph.D. (Princeton) Brown Univ., Providence, R. I. *44 E. Manning St.*

GINGRICH, Prof. C. H., Ph.D. (Chicago) Math. and Astr., Carleton Coll., Northfield, Minn.

GINNINGS, R. M., M.S. (Chicago) Head of Dept., Western Illinois State Teachers Coll., Macomb, Ill. *314 N. Ward St.*

GITHENS, C. E., Ph.D. (Franklin) Instr., Kiskiminetas Springs School, Saltsburg, Pa.

GLAZIER, Asst. Prof. HARRIET E., A.M. (Chicago) Univ. of California at Los Angeles, Los Angeles, Calif. *1307 Lucile Ave.*

GLEASON, J. M., A.M. (California) Instr., State Teachers Coll., San Diego, Calif.

GLOVER, Prof. B. C., A.M. (Chicago) Otterbein Coll., Westerville, Ohio. *220 Hiawatha Ave.*

GLOVER, J. W., Ph.D. (Harvard) Pres., Teachers Ins. and Annuity Assn., New York, N. Y. *522 Fifth Ave., Rm. 912.*

GOLD, Asst. Prof. J. S., B.S. (Bucknell) Bucknell Univ., Lewisburg, Pa. *306 S. Third St.*

GOLDBERG, MICHAEL, A.M. (George Washington) Engineer, Bureau of Ordnance, Navy Dept., Washington, D. C. *2816 Connecticut Ave.*

GORDON, W. O., A.B. (Bowdoin) Instr., Pennsylvania State Coll., State College, Pa. *Dept. of Math.*

GORRELL, Prof. G. W., A.M. (Ohio State) Univ. of Denver, Denver, Colo. *2236 S. Milwaukee St.*

GOSNELL, L. P., A.M. (George Washington) Statistician, George Washington Univ., Washington, D. C. *1205 15th St. N.W.*

GOULD, ALICE B., A.B. (Bryn Mawr) Care W. W. Vaughan, 53 State St., Boston, Mass.

GOUWENS, Asso. Prof. CORNELIUS, Ph.D. (Chicago) Iowa State Coll., Ames, Iowa. *109 N. Hyland Ave.*

GRABER, Prof. M. E., Ph.D. (Iowa) Physics, Morningside Coll., Sioux City, Iowa.

GRAESSER, Asst. Prof. R. F., Ph.D. (Illinois) Univ. of Arizona, Tucson, Ariz. *Dept. of Math.*

GRAHAM, MABEL S. (Mrs. F. W.), A.M. (New Mexico) Albuquerque, N. Mex. *Box 528.*

GRAHAM, MARIA D., A.M. (Columbia) E. Carolina Teachers Coll., Greenville, N. C.

GRAHAM, Prof. P. H., A.M. (Virginia) Washington Square Coll., New York Univ., New York, N. Y.

GRANT, ALICE A., A.M. (Brown) Winthrop Coll., Rock Hill, S. C. *Dept. of Math.*

GRANT, Prof. E. D., Ph.D. (Chicago) Math. and Registrar, Earlham Coll., Richmond, Ind. *330 College Ave.*

GRANT, J. D., M.S. (Michigan), A.M. (Illinois) Asst., Univ. of Illinois, Urbana, Ill. *649 Congress St., Indianapolis, Ind.*

GRAUSTEIN, Asso. Prof. W. C., Ph.D. (Bonn) Harvard Univ., Cambridge, Mass. *32 Shepard St.*

GRAVATT, Prof. T. E., M.S. (Rutgers) Pennsylvania State Coll., State College, Pa.

GRAVES, Asso. Prof. G. H., Ph.D. (Columbia) Purdue Univ., W. LaFayette, Ind. *829 Main St.*

GRAVES, Asso. Prof. L. M., Ph.D. (Chicago) Univ. of Chicago, Chicago, Ill. *1201 E. 60th St.*

GREEN, Prof. R. L., A.M. (Indiana) Emeritus, Stanford Univ., Stanford University, Calif. *541 Salvatierra St.*

GREENLEAF, Asso. Prof. H. E. H., A.M. (Boston) DePauw Univ., Greencastle, Ind. *1024 S. College Ave. On leave 1931–32, Indiana Univ.*

GRIFFIN, Prof. F. L., Ph.D. (Chicago) Reed Coll., Portland, Ore.

GRIFFIN, HARRIET M., A.M. (Columbia) Instr., Hunter Coll., New York, N. Y. *918 76th St., Brooklyn, N. Y.*

GRIFFITHS, Asst. Prof. LOIS W., Ph.D. (Chicago) Northwestern Univ., Evanston, Ill. *Dept. of Math.*

GRIMES, Prof. N. C., A.M. (Wisconsin) Grove City Coll., Grove City, Pa. *415 Woodland Ave.*

GROVE, Prof. C. C., Ph.D. (Johns Hopkins) School of Commerce, Coll. of the City of New York, New York, N. Y. *143 Milburn Ave., Baldwin, L. I., N. Y.*

GROVE, Asso. Prof. V. G., Ph.D. (Chicago) Michigan State Coll., East Lansing, Mich. *212 W. Grand River Ave.*

GRUMMANN, Asst. Prof. H. R., A.M. (Minnesota) Washington Univ., St. Louis, Mo. *Faculty Box 103.*

GUMMER, Prof. C. F., Ph.D. (Chicago) Queen's Univ., Kingston, Ont., Can. *143 Collingwood St.*

GUMMERE, H. V., A.M. (Harvard) Lecturer in Astr., Haverford Coll., Haverford, Pa.
GUNDERSEN, Prof. CARL, Ph.D. (Columbia) Oklahoma A. and M. Coll., Stillwater, Okla. *615 College Ave.*
GUNN, GRACE T., A.M. (Northwestern) Instr., Univ. of Omaha, Omaha, Nebr. *24th and Pratt St.*
GUNSTAD, BORGHILD, B.S. (Minnesota) Asst. in Botany, Univ. of Minnesota, Minneapolis, Minn. *3245 Nicollet Ave.*
GUTTMAN, SOLOMON. 1801 Sixth Ave. N., Minneapolis, Minn.
GWINN, Asst. Prof. I. J., M.S. (Iowa) Physics and Math., Morningside Coll., Sioux City, Iowa.
GWINNER, Prof. HARRY, M.E. (Maryland) Eng. Math., Univ. of Maryland, College Park, Md. *Box 242.*

HAAS, ARTHUR, A.B. (C.C.N.Y.), LL.B. (New York Univ.) Chm. Dept., Thomas Jefferson High School, Brooklyn, N. Y. *Dumont and Pennsylvania Aves.*
HACKER, S. G., A.B. (Colorado) Asst. in Astr., Princeton Univ., Princeton, N. J.
HACKNEY, LILIAN, A.B. (West Virginia) Marshall Coll., Huntington, W. Va.
HADAMARD, Prof. JACQUES, LL.D. (Yale) École Polytech. et Coll. de France, Paris, France. *25 rue de Jean Dolent, Paris (14e).*
HADLEY, Prof. LAURENCE, Ph.D. (Michigan) Purdue Univ., W. LaFayette, Ind. *121 Lutz Ave.*
HADLEY, S. M., Ph.D. (Wisconsin) Whittier Coll., Whittier, Calif.
HADLOCK, E. H. Instr., Cornell Univ., Ithaca, N. Y. *614 E. Buffalo St.*
HAERTTER, L. D., A.M. (Columbia) John Burroughs School, Clayton, Mo.
HAGGARD, H. W., B.S. (Denison) Instr., Armour Inst. of Tech., Chicago, Ill. *940 E. 56th St., Hyde Park Sta.*
HALDEMAN, C. B. Ross, Butler Co., Ohio.
HALL, F. C., A.M. (Columbia) Grad. Student, Columbia Univ., New York, N. Y. *435 W. 119 St., Apt. 10 C.*
HALL, Prof. H. L., A.B. (Indiana) Northwestern State Teachers Coll., Alva, Okla. *923 Seventh St.*
HALL, RUTH H., A.B. (Brown) Dana Hall, Wellesley, Mass.
HALL, Prof. W. S., Sc.D. (Gettysburg) Lafayette Coll., Easton, Pa. *College Campus.*
HALPERIN, Prof. HILLEL, E.E. (Liége), A.M. (Columbia) A. and M. Coll. of Texas, College Station, Tex.
HAMILTON, J. A., B.A. (Queen's Univ.) Instr., Pennsylvania State Coll., State College, Pa. *Dept. of Math.*
HAMILTON, W. M., A.M. (Michigan) Asst., U. S. Nautical Almanac Office, U. S. Naval Observ., Washington, D. C.
HAMMOND, Prof. E. S., Ph.D. (Princeton) Bowdoin Coll., Brunswick, Me. *84 Federal St.*
HAMPTON, LAURENCE, A.M. (Nebraska) Instr., Alabama Poly. Inst., Auburn, Ala. *Box 72.*
HANAWALT, Prof. F. W., A.M. (DePauw) Math. and Astr., Coll. of Puget Sound, Tacoma, Wash. *826 N. Steele St.*
HANCOCK, CLARA L., A.M. (Iowa) Instr., Jr. Coll., Virginia, Minn. *331½ Fifth St. S.*
HANCOCK, Prof. HARRIS, Ph.D. (Berlin) Univ. of Cincinnati, Cincinnati, Ohio.
HANDY, Mrs. LOUISE L., A.B. (Michigan) Long Beach, Calif.
HANNA, Prof. U. S., Ph.D. (Pennsylvania) Indiana Univ., Bloomington, Ind. *828 Atwater Ave.*
HANSON, H. O., A.B. (Columbia) Mut. Life Ins. Co., Corona, L. I., N. Y. *106–30 Ditmars Blvd.*
HANTHORN, EMMA E., A.B. (Nebraska) Teacher, State Teachers Coll., Kearney, Nebr.
HAPPELL, G. E., A.M. (Nebraska) Instr., Purdue Univ., W. Lafayette, Ind. *707 Hayes St.*
HARDING, Prof. A. M., Ph.D. (Chicago) Dir., Genl. Extension Service, Univ. of Arkansas, Fayetteville, Ark. *537 Leverett St.*
HARDING, HOWARD, B.M.E. (Michigan) Rochester Gas and Elec. Corp., Rochester, N. Y. *29 Kingston St.*
HARDING, J. C. D., A.B. (Pennsylvania) Instr., Univ. of Delaware, Newark, Del. *Mansion Apts., Lansdowne, Pa.*
HARDY, G. H. Trinity Coll., Cambridge, England.
HARDY, Prof. J. G., Ph.D. (Johns Hopkins) Williams Coll., Williamstown, Mass.
HARKIN, Asso. Prof. D. C., Ph.D. (Chicago) Alabama Poly. Inst., Auburn, Ala.
HARMOUNT, G. P., A.M. (Ohio State) Head of Dept., East High School, Columbus, Ohio. *2290 Indianola Ave.*
HARP, E. L., Jr. Asst., Univ. of New Mexico, Albuquerque, N. Mex.
HARPER, H. D., Sc.B. (New York Univ.) Instr., Murray Hill Voc. School, New York, N. Y. *3457 72nd St., Jackson Hts., N. Y.*

HARRELL, Prof. J. W., A.M. (Brown) Head of Dept., Baylor Univ., Waco, Tex.
HARRINGTON, Asst. Prof. C. E., M.E. (Cornell, M.S. (Buffalo) Asst. to the Dean, Univ. of Buffalo, Buffalo, N. Y. *52 Winter St.*
HARRIS, Mrs. D. P. 102 Middle St., Louisburg, N. C.
HARRIS, ELIZABETH L., M.S. (Washington Univ.) Computer, Southwestern Bell Tel. Co., St. Louis, Mo. *336 W. Madison Ave., Kirkwood, Mo.*
HARRIS, Asso. Prof. ISABEL, A.M. (Columbia) Westhampton Coll., Univ. of Richmond, Richmond, Va.
HARRIS, MARGARET E., A.M. (Teachers Coll., Columbia) Chair of Math., Grenada Coll., Grenada, Miss.
HARRY, S. C., A.B. (Johns Hopkins) Head of Dept., City Coll., Baltimore, Md. *1528 Linden Ave.*
HARSHBARGER, FRANCES, Ph.D. (Illinois) Head of Dept., Constantinople Women's Coll., Istanbul, Turkey. *Galata Post Office, Box 39.*
HARSHBARGER, Prof. W. A., Sc.D. (Washburn) Washburn Coll., Topeka, Kans. *1401 College Ave.*
HART, BERTHA I., A.M. (Cornell) 316 Fayette St., Cumberland, Md.
HART, Prof. J. N., C.E. (Maine), M.S. (Chicago) Univ. of Maine, Orono, Me. *123 Main St.*
HART, Prof. W. L., Ph.D. (Chicago) Univ. of Minnesota, Minneapolis, Minn.
HART, Asso. Prof. W. W., A.B. (Chicago) Univ. of Wisconsin, Madison, Wis. *R.F.D. 7.*
HARTER, Prof. G. A., M.A. (St. John's) Univ. of Delaware, Newark, Del.
HARTIG, Asst. Prof. H. E., Ph.D. (Minnesota) Math. and Mech., Univ. of Minnesota, Minneapolis, Minn.
HARTNELL, GEORGE. Observer in charge, Cheltenham Magn. Observ., Cheltenham, Md.
HARTUNG, M. L., Ph.D. (Wisconsin) Instr., Teaching of Math., Wisconsin High School, Madison, Wis.
HARTWICK, Prof. F. C., M.Sc. (Fribourg, Switzerland) Prin., Chaminąde High School, Dayton, Ohio. *108 Franklin St.*
HARWOOD, Asst. Prof. MAY N., A.M. (Syracuse) Syracuse Univ., Syracuse, N. Y. *200½ Waverly Ave.*
HASKELL, Prof. M. W., Ph.D. (Göttingen) Univ. of California, Berkeley, Calif. *P. O. Box 3.*
HASKELL, R. N., Ph.D. (Rice) 478 Tell St., Vevay, Ind.
HASSLER, Prof. J. O., Ph.D. (Chicago) Univ. of Oklahoma, Norman, Okla. *425 Lahoma Ave.*
HATCH, Asso. Prof. D. A., Eng. of Mines (Lafayette) Lafayette Coll., Easton, Pa. *705 High St.*
HATCHER, Asso. Prof. T. W., M.E. (Va. Poly. Inst.), M.S. (Iowa State Coll.) Virginia Poly. Inst., Blacksburg, Va. *Box 476.*
HATFIELD, Prof. CHARLES, A.M. (Tennessee) Georgetown Coll., Georgetown, Ky.
HATHAWAY, Prof. A. S., B.S. (Cornell) Retired, Rose Poly. Inst. *Boerne, Tex.*
HAVILAND, E. K., Ph.D. (Harvard) Grad. Student., Johns Hopkins Univ., Baltimore, Md. *Port Deposit, Md.*
HAWKES, Dean H. E., Ph.D. (Yale) Columbia Univ., New York, N. Y. *Hamilton Hall.*
HAYASHI, Prof. TSURUICHI, M.Sc. (Tokyo Imper. Univ.), D.Sc. (Government) Emeritus, Coll. of Science, Tohoku Imperial Univ., Sendai, Japan. *Kamoncho 10.*
HAZARD, Asso. Prof. C. T., A.M. (Indiana) Purdue Univ., W. LaFayette, Ind., *344 N. Western Ave.*
HAZELTINE, Prof. B. A., B.S. (Tufts) Dean of Men, Middlebury Coll., Middlebury, Vt. *38 South St.*
HAZLETT, Asso. Prof. OLIVE C., Ph.D. (Chicago) Univ. of Illinois, Urbana, Ill. *Box 574, Sta. A., Champaign, Ill.*
H'DOUBLER, F. T., Ph.D. (Wisconsin), M.D. (Harvard) Surgeon, Springfield, Mo. *804 Medical Arts Bldg.*
HEATH, Prof. D. F., A.M. (Illinois) Franklin Coll., Franklin, Ind. *700 E. Jefferson St.*
HEDRICK, Prof. E. R., Ph.D. (Göttingen) Univ. of California at Los Angeles, Los Angeles, Calif.
HENFER, R. A., Ph.D. (Chicago) Instr., Georgia School of Tech., Atlanta, Ga. *946 Juniper St.*
HEINS, A. E. Student, Mass. Inst. of Tech., Cambridge, Mass. *127 Homes Ave., Dorchester, Mass.*
HENDERSON, Prof. ARCHIBALD, Ph.D. (North Carolina; Chicago) Head of Dept. Univ. of North Carolina, Chapel Hill, N. C. *721 E. Franklin St.*
HENDERSON, ROBERT, D.Sc. (Toronto) Vice-Pres. and Actuary, Equitable Life Assur. Soc., New York, N. Y. *393 Seventh Ave.*
HENDRICKS, A. F., B.S. (Valparaiso) Pres. Emeritus, Mayfield Coll., Marble Hill, Mo. *Wingate, N. C.*
HENDRICKS, S. F., A.B. (Berea) Grad. Asst., Univ. of Kentucky, Lexington, Ky. *182 E. High St.*

HENNEL, Asso. Prof. CORA B., Ph.D. (Indiana) Indiana Univ., Bloomington, Ind. *822 Atwater Ave.*
HENROTEAU, F. C., Dr. of Physics and Math. (Brussels) Head of Astrophys. Dept., Dominion Observ., Ottawa, Ont., Can.
HENRY, ETTA M., B.S. (Michigan) 60 E. Valley Stream Blvd., Valley Stream, N. Y.
HEREN, Asst. Prof. MABEL M., M.S. (Northwestern) Knox Coll., Galesburg, Ill.
HERR, Asso. Prof. GERTRUDE A., M.S. (Iowa State Coll.) Iowa State Coll., Ames, Iowa.
HERRON, Prof. C. L., A.M. (Hillsdale) Hillsdale Coll., Hillsdale, Mich. *118 Hillsdale St.*
HESS, Asso. Prof. G. W., Ph.D. (Michigan) Howard Univ., Birmingham, Ala. *8009 Berney Ave.*
HESSELTINE, EVELYN, A.M. (Nebraska) Teacher, Normal School, Spearfish, S. D.
HICKEY, Prof. DEBORAH M., Ph.D. (Rice) Delta State Teachers Coll., Cleveland, Miss.
HICKS, Prof. H. C., Ph.D. Carnegie Inst. of Tech., Pittsburgh, Pa. *906 Kennebec St.*
HICKSON, Asst. Prof. A. O., Ph.D. (Chicago) Duke Univ., Durham, N. C.
HIGGINS, VIRGINIA I., A.B. (Marquette) Teacher, French Inst. of Notre Dame de Sion, Kansas City, Mo.
HIGH, M. DETURK, A.B. (Franklin and Marshall) Head of Dept. and Dean of Men, State Teachers Coll., Lock Haven, Pa.
HIGHTOWER, Prof. RUBY U., Ph.D. (Missouri) Shorter Coll., Rome, Ga.
HILDEBRANDT, MARTHA, M.S. (Chicago) Teacher, Proviso High School, Maywood, Ill. *808 S. Second Ave.*
HILDEBRANDT, Prof. T. H., Ph.D. (Chicago) Univ. of Michigan, Ann Arbor, Mich. *1930 Cambridge Rd.*
HILDNER, R. C., B.S. (Wooster) Grad. Asst., Ohio State Univ., Columbus, Ohio. *Dept. of Math.*
HILL, Prof. A. L., A.B. (Doane) Math. and Physics, State Teachers Coll., Peru, Nebr.
HILL, J. D., A.B. (U.C.L.A.) Univ. of California at Los Angeles, Los Angeles, Calif. *1116 S. Windsor Blvd.*
HILL, Asso. Prof. L. S., Ph.D. (Yale) Hunter Coll., New York, N. Y. *1180 Anderson Ave.*
HILL, Asst. Prof. M. A., Jr., A.M. (North Carolina) Univ. of North Carolina, Chapel Hill, N. C. *Box 215.*
HILL, Adj. Prof. P. R., M.S. (Georgia) Univ. of Georgia, Athens, Ga. *190 Morton Ave.*
HILL, Prof. R. E., A.M. (Louisville) Head of Dept., Univ. of Louisville, Louisville, Ky. *113 Coral Ave.*
HILL, Prof. W. H., A.M. (Colorado) State Teachers Coll., Pittsburg, Kans. *1612 S. Walnut St.*
HILLARD, Asso. Prof. C. R., A.M. (Columbia) Wheaton Coll., Wheaton, Ill.
HILLE, Asso. Prof. EINAR, Ph.D. (Stockholm) Princeton Univ., Princeton, N. J. *174 Prospect Ave.*
HINSCH, Asso. Prof. V. B., E.M. (Missouri School of Mines) School of Mines and Metallurgy, Rolla, Mo.
HIRSCH, BLANCHE, B.S. (Columbia) Prin., Alcuin Prep. School, New York, N. Y. *48 W. 86th St.*
HIRSCHLER, Prof. E. J., M.S. (Chicago) Bluffton Coll., Bluffton, Ohio.
HITCHCOCK, Prof. R. R., A.M. (Northwestern) Univ. of North Dakota, University, N. D.
HOARE, Prof. A. J., A.M. (Michigan) Head of Dept., Univ. of Wichita, Wichita, Kans. *1717 Holyoke Ave.*
HOBENSACK, CLARICE S., A.M. (Ohio State) Ludlow and Telford St., Cincinnati, Ohio.
HODGE, Asst. Prof. F. H., A.M. (Boston) Purdue Univ., W. LaFayette, Ind. *820 N. Main St.*
HOLDER, Prof. F. J., Ph.D. (Yale) Math., and Dean of School of Commerce, Mercer Univ., Macon, Ga. *912 College St.*
HOLGATE, Prof. T. F., Ph.D. (Clark) Northwestern Univ., Evanston, Ill. *617 Library Pl.*
HOLLCROFT, Prof. T. R., Ph.D. (Cornell) Wells Coll., Aurora, N. Y.
HOLLIS, ELINOR V., M.S. (Chicago) The Madeira School, Greenway, Va. *Fairfax Co.*
HOLLOWAY, W. R. Prin., High School, Basco, Ill.
HOLMES, Dean C. F., M.S. (Howard) Texas Coll., Tyler, Tex.
HOLMES, Asst. Prof. C. T., A.M. (Harvard) Bowdoin Coll., Brunswick, Me. *6 Longfellow Ave.*
HOLMES, Asst. Prof. F. F., A.B. (Amherst) Norwich Univ., Northfield, Vt. *12 Byam St.*
HOLT, E. W., A.B. (Colgate) 7 Jefferson St., Attleboro, Mass.
HOME, MAURICE S., M.S. (McGill) Lecturer, Physics and Appl. Math., Univ. of Bishops Coll., Lennoxville, P. Q., Can.
HOOK, C. W., A.M. (North Carolina) Instr., Georgia School of Tech., Atlanta, Ga.
HOOPES, M. F., A.B. (Oberlin) Teacher, Southern State Teachers Coll., Springfield, S. D.
HOOVER, Asso. Prof. B. P., Ph.D. (Illinois) Carnegie Inst. of Tech., Pittsburgh, Pa. *2040 Fairlawn Ave., Wilkinsburg Manor.*

HOPKINS, FANNIE, A.B. (Franklin) 234 E. Park Ave., Waukesha, Wis.
HOPKINS, Asso. Prof. L. A., Ph.D. (Chicago) Univ. of Michigan, Ann Arbor, Mich.
HOPPER, GRACE M., A.M. (Yale) Asst., Vassar Coll., Poughkeepsie, N. Y. *40 Morningside Ave., New York, N. Y.*
HORN, MARVEL C., A.M. (Ohio State) Teacher, High School, Columbus, Ohio. *69 Sherman Ave.*
HORSBURGH, E. M., D.Sc. (Edinburgh) Lecturer in Technical Math. and Eng. Dyn., Univ. of Edinburgh, Edinburgh, Scotland. *11 Granville Ter.*
HORSFALL, I. O., A.M. (Chicago) Instr., Cornell Univ., Ithaca, N. Y. *119 Blair St.*
HORTON, Adj. Prof. GOLDIE P., Ph.D. (Texas) Pure Math., Univ. of Texas, Austin, Tex. *2402 Windsor Rd.*
HOSFORD, Prof. H. M., Ph.D. (Illinois) Univ. of Arkansas, Fayetteville, Ark.
HOSKINS, Prof. L. M., C.E. (Wisconsin) Emeritus, Stanford Univ. *1240 Waverly St., Palo Alto, Calif.*
HOUSEHOLDER, Asst. Prof. A. S., A.M. (Cornell) Washburn Coll., Topeka, Kans.
HOUSEHOLDER, Asso. Prof. F. C., A.B. (Kansas) North Dakota Agric. Coll., Fargo, N. D. *1114–13th St. N.*
HOWARD, Prof. C. M., E.Mines (Ala. Poly. Inst.) Texas Woman's Coll., Fort Worth, Tex. *3318 Ave. I.*
HOWARD, Prof. W. E., Ph.D. (Indiana) Head of Dept., Univ. of Tulsa, Tulsa, Okla.
HOWE, ANNA M., Ph.D. Box 245, Jordan, N. Y.
HOWE, G. K., B.S. (Worcester Poly. Inst.) Treasurer, Tougaloo Coll., Tougaloo, Miss.
HOWIE, Prof. J. M., A.M. (Columbia) Nebraska Wesleyan Univ., Lincoln, Nebr. *5218 Walker Ave.*
HOWLAND, Prof. L. A., Ph.D. (Munich) Fisk Prof. of Math., Wesleyan Univ., Middletown, Conn. *34 Home Ave.*
HOYT, R. S., M.S. (Princeton) Telephone Research Engr., Amer. Tel. and Tel. Co., New York, N. Y. *195 Broadway.*
HUBBS, Asst. Prof. H. N., A.M. (Rochester) Hobart Coll., Geneva, N. Y. *251 Washington St.*
HUBER, Prof. C. M., Ph.D. (Illinois) Head of Dept. and Dir. of Extension, Atlantic Univ. Virginia Beach, Va.
HUBERT, Asso. Prof. W. G., Sc.D. (New York Univ.) Coll. of the City of New York. *125 Lee Ave., Yonkers, N. Y.*
HUFFER, Asso. Prof. R. C., A.M. (Illinois) Beloit Coll., Beloit, Wis. *729 Hobart Pl.*
HUGHES, Asst. Prof. H. K., Ph.D. (Michigan) Purdue Univ., W. LaFayette, Ind. *617 Dodge St.*
HUGHES, Asst. Prof. JEWELL C., Ph.D. (Chicago) Hunter Coll., New York, N. Y. *605 W. 115 St.*
HUGHES, W. M., A.M. (Baylor) 517 Texas St., Denton, Tex.
HUME, Pres. ALFRED, D.Sc. (Vanderbilt) Branham and Hughes Milit. Acad., Spring Hill, Tenn.
HUNT, Asst. Prof. G. H., C.E. (Cornell) Univ. of California at Los Angeles, Los Angeles, Calif. *926 Hyperion Ave.*
HUNT, Prof. MILDRED, Ph.D. (Chicago) Illinois Wesleyan Univ., Bloomington, Ill. *1211 Fell Ave.*
HUNTINGTON, A. H., A.M. (Columbia) Asst. Prin., Beaumont High School, St. Louis, Mo. *736 Fairview Ave., Webster Groves, Mo.*
HUNTINGTON, Prof. E. V., Ph.D. (Strassburg) Mech., Harvard Univ., Cambridge, Mass.
HURRY, Prof. J. A., A.M. (California) Head of Dept., Physics, Jr. Coll., San Antonio, Tex.
HURST, Asso. Prof. J. W., Ph.D. (Illinois) State Coll., Bozeman, Mont. *621 S. 7th St.*
HURWITZ, SOLOMON, A.M. (Columbia) Instr., Townsend Harris Hall High School, New York, N. Y. *1601 University Ave., Bronx.*
HURWITZ, Prof. W. A., Ph.D. (Göttingen) Cornell Univ., Ithaca, N. Y. *White Hall 8.*
HUSSEY, L. W., A.M. (Harvard) 55 Monroe Pl., Bloomfield, N. J.
HUTCHERSON, Prof. W. R., Ph.D. (Cornell) Head of Dept., Berea Coll., Berea, Ky.
HUTCHINS, MABEL, A.B. (Blue Mountain) Head of Dept., Blue Mountain Coll., Blue Mountain, Miss.
HUTCHINSON, Prof. C. A., A.M. (Wittenberg) Eng. Math., Univ. of Colorado, Boulder, Colo. *837 Fifteenth St.*
HUTCHINSON, JEAN A., A.B. (Hunter) Substitute, Hunter Coll., New York, N. Y. *410 Park Ave.*
HYDE, Asso. Prof. EMMA, A.M. (Chicago) State Agric. Coll., Manhattan, Kans.

ICAMEN, B. R., A.B. (Occidental), B.S.C.E. (South Carolina) Acting Head of Dept., Silliman Inst., Maasin, Leyte, P. I.

ILOFF, Prof. P. M., A.M. (Michigan) State Teachers Coll., Chico, Calif. *1329 Esplanade.*
INGALLS, E. E., M.S. (Iowa) Albion Coll., Albion, Mich. *416 E. Cass St.*
INGOLD, Prof. BYRON, A.M. (Central Wesleyan) Culver-Stockton Coll., Canton, Mo.
INGOLD, Prof. LOUIS, Ph.D. (Chicago) Univ. of Missouri, Columbia, Mo. *206 Thilly Ave.*
INGRAHAM, Prof. M. H., Ph.D. (Chicago) Univ. of Wisconsin, Madison, Wis. *Dept. of Math.*
IRWIN, Asso. Prof. FRANK, Ph.D. (Harvard) Univ. of California, Berkeley, Calif. *2921 Regent St.*
ISAACS, Prof. C. A., A.M. (Columbia) Head of Dept., State Coll., Pullman, Wash.
IVANOFF, V. F., A.B. (California) Grad. Student, Univ. of California, Berkeley, Calif. *1646–26th Ave., San Francisco, Calif.*

JABLONOWER, JOSEPH, Pd.M. (New York Univ.) Teacher, Fieldston School, New York, N. Y. *238th St. and Riverdale Ave.*
JACKSON, Prof. DUNHAM, Ph.D. (Göttingen) Univ. of Minnesota, Minneapolis, Minn. *119 Folwell Hall.*
JACKSON, Prof. J. B., A.M. (Columbia) Univ. of South Carolina, Columbia, S. C. *227 S. Waccamaw Ave.*
JACKSON, Prof. ROSA L., Ph.D. (Chicago) Alabama Coll., Montevallo, Ala.
JAEGER, Prof. C. G., Ph.D. (Missouri) Pomona Coll., Claremont, Calif. *1224 Harvard Ave.*
JAMES, Asso. Prof. GLENN, Ph.D. (Columbia) Univ. of California at Los Angeles, Los Angeles, Calif. *405 Hilgard Ave., Brentwood Hts. Sta.*
JAMISON, Prof. G. H., A.M. (Chicago) State Teachers Coll., Kirksville, Mo. *Box 116.*
JANES, Asst. Prof. W. C., A.M. (Nebraska) State Agric. Coll., Manhattan, Kans.
JARRETT, ETHEL L., A.B. (Cornell) Chicago Latin School for Girls, Chicago, Ill. *59–69 Scott St.*
JEFFERS, H. M., Ph.D. (California) Asst. Astronomer, Lick Observ., Mt. Hamilton, Calif.
JEFFERY, R. L., Ph.D. (Cornell) Acadia Univ., Wolfville, N. S.
JEKEL, A. H., A.B. (Michigan) Box 296, Boulder, Colo.
JENKINS, W. A., A.M. (Michigan) 308 S. Seminole Circle, Fort Wayne, Ind.
JENSEN, Asst. Prof. C. M., Ph.D. (Minnesota) Macalester Coll., St. Paul, Minn. *3315 17th Ave. S., Minneapolis, Minn.*
JERBERT, Asst. Prof. A. R., Ph.D. (Washington) Univ. of Washington, Seattle, Wash. *4824–38 N.E.*
JEROME, Prof. JESSIE M., A.M. (Hiram) Hiram Coll., Hiram, Ohio.
JIMENEZ, Rev. FELIPE, B.S. (Notre Dame) Colegio de San Juan de Letran, Manila, P.I. *200 Beaterio St.*
JOFFE, S.A., M.S. (New York Univ.) Asst. Actuary, Mut. Life Ins. Co., New York, N. Y. *32 Nassau St.*
JOHN, F. W., M.E. (Cornell) Instr., Washington Square Coll., New York Univ., New York, N. Y. *199 N. Broadway, Yonkers, N. Y.*
JOHNSON, ABIGAIL E., A.M. (Columbia) Head of Dept., High School, Morristown, N. J. *2 Rosedale Ave., Morris Plains, N. J.*
JOHNSON, Prof. B. F., A.M. State Teachers Coll., Cape Girardeau, Mo. *530 N. Pacific St.*
JOHNSON, C. L., B.S. (Ore. Agric.) Head of Dept., Oregon Agric. Coll., Corvallis, Ore. *1001 Jefferson St.*
JOHNSON, E. H., A.M. (Lehigh) Instr., Univ. of Detroit, Detroit, Mich. *17130 Birchcrest Dr.*
JOHNSON, Prof. E. N., A.M. (Drake), M.S. (Kansas) Butler Coll., Indianapolis, Ind. *304 Downey Ave.*
JOHNSON, H. F., A.M. (Cincinnati) State Teachers Coll., Bowling Green, Ky.
JOHNSON, Asst. Prof. MARIE M., Ph.D. (Chicago) Oberlin Coll., Oberlin, Ohio. *116 Elm St.*
JOHNSON, Asso. Prof. R. A., Ph.D. (Harvard) Brooklyn Coll., Brooklyn, N. Y. *66 Court St.*
JOHNSON, Asso. Prof. R. P., A.M. (Virginia; Harvard) Carnegie Inst. of Tech., Pittsburgh, Pa. *Dept. of Math.*
JOHNSON, W. W. Instr., Applied Math. and Mech., Cleveland Y.M.C.A. School of Tech., Cleveland, Ohio. *1394 E. 109th St.*
JOHNSTON, Asso. Prof. F. E., Ph.D. (Illinois) George Washington Univ., Washington, D.C.
JOHNSTON, Asst. Prof. K. P., B.A., B.Sc. (Queen's) Queen's Univ., Kingston, Ont., Can. *Dept. of Math.*
JOHNSTON, Asso. Prof. L. S., A.M. (Missouri) Coll. of Eng., Univ. of Detroit, Detroit, Mich.
JOHNSTON, NELLIE M., A.B (Kearney State Teachers Coll.) Warren Twp. High School, Gurnee, Ill.
JONAH, Asst. Prof. F. C., Ph.D. (Brown) Adelbert Coll., Western Reserve Univ., Cleveland, Ohio.

JONES, AGNES A. Larimer, Pa.
JONES, Asst. Prof. B. W., Ph.D. (Chicago) Cornell Univ., Ithaca, N. Y. *Dept. of Math.*
JONES, Prof. E. H., A.M. (Harvard) Southern Methodist Univ., Dallas, Tex.
JONES, MARGARET E., A.M. (Ohio State) Instr., Ohio State Univ., Columbus, Ohio. *164–13th Ave.*
JONES, OLIVE M., A.M. (Columbia) Head of Dept., Queen's-Chicora Coll., Charlotte, N. C.
JONES, P. C., B.S. (Mass. Inst. of Tech.) Bureau of Publication, Bell Telephone Labs., New York, N. Y. *463 West St.*
JONES, Asst. Prof. R. W., M.S. (Delaware), A.M. (Pennsylvania) Univ. of Delaware, Newark, Del. *204 W. 17th St., Wilmington, Del.*
JONES, S. I., B.S. (N. Tex. Normal Coll.) Asst. Secy. and Treas., Life and Casualty Ins. Co., Nashville, Tenn.
JORDAN, Asst. Prof. E. E., M.A. (Dalhousie) Univ. of British Columbia, Vancouver, B.C., Can. *4195 W. 15th Ave.*
JORDAN, Asso. Prof. H. E., Ph.D. (Chicago) Univ. of Kansas, Lawrence, Kans. *1600 Kentucky St.*
JORDAN, Asso. Prof. M. F., A.M. (Maine) Astr., Univ. of Maine, Orono, Me.
JORDAN, Prof. WILLIAM, A.M. (DePauw) Head of Dept., Oakland City Coll., Oakland City, Ind.
JOSE, P. D., A.M. (Syracuse) Instr., Syracuse Univ., Syracuse, N. Y. *618 Allen St.*
JUDD, L. W. Jr. Engineer, Panama Canal, Canal Zone. *Box Q, Balboa Hts.*
JURDAK, Prof. M. H., M.A. (Amer. Univ. of Beirut) American Univ. of Beirut, Beirut, Syria.
JUSTICE, Asst. Prof. H. K., C.E. (Cincinnati) Univ. of Cincinnati, Cincinnati, Ohio. *4767 High Ridge Ave., Price Hill.*
JUSTIN, E. M., M.S. (Case School) Case School of Appl. Science, Cleveland, Ohio.

KALTENBORN, H. S., M.S. (Michigan) Instr., Carnegie Inst. of Tech., Pittsburgh, Pa. *617 Hale St., Wilkinsburg Sta.*
KANIES, ELIZABETH S. (Mrs. W. F.), 7907 Sunset Drive, Elmwood Park, Chicago, Ill.
KARAPETOFF, Prof. VLADIMIR, M.M.E. (Leningrad) Elec. Eng., Cornell Univ., Ithaca, N. Y. *520 E. Buffalo St.*
KARNOW, HERMAN, A.M. (Colorado) 230 Liberty Ave., Brooklyn, N. Y.
KARPINSKI, Prof. L. C., Ph.D. (Strassburg) Univ. of Michigan, Ann Arbor, Mich. *1315 Cambridge Rd.*
KARR, LOIS, A.M. (Wisconsin) Instr., Lindenwood Coll., St. Charles, Mo.
KASNER, Prof. EDWARD, Ph.D. (Columbia) Columbia Univ., New York, N. Y. *22 W. 119th St.*
KAZARINOFF, K., Agrégé (Moscow) Instr., Univ. of Michigan, Ann Arbor, Mich. *1515 Cambridge Rd.*
KEARNEY, DORA E., A.M. (Minnesota) State Teachers Coll., Cedar Falls, Iowa. *1310 W. 22nd St.*
KEELER, C. A., A.M. (California) Grad. Student, Univ. of California, Berkeley, Calif. *2426 Fulton St.*
KEITH, Asst. Prof. MARY N., A.B. (Wellesley) Univ. of Redlands, Redlands, Calif. *930 Campus Ave.*
KELLAM, C. E., A.M. (Chicago) Head of Dept., East Chicago High Schools, East Chicago, Ind. *4239 Baring Ave.*
KELLOGG, Prof. O. D., Ph.D. (Göttingen) Harvard Univ., Cambridge, Mass. *18 Craigie St.*
KELLS, Asst. Prof. L. M., Ph.D. (Columbia) U. S. Naval Acad., Annapolis, Md. *23 Thompson St.*
KELLY, K. D., M.S. (Chicago) Georgetown, Ind.
KEMPNER, Prof. A. J., Ph.D. (Göttingen) Head of Dept., Univ. of Colorado, Boulder, Colo.
KENDALL, Asso. Prof. CLARIBEL, Ph.D. (Chicago) Univ. of Colorado, Boulder, Colo. *1305 Euclid Ave.*
KENNEDY, Adj. Prof. E. C., A.M. (Texas) Coll. of Mines, El Paso, Tex.
KENNEDY, KATHRYN M., A.M. (Columbia) Critic, Coll. Training High School, Terre Haute, Ind.
KENNELLY, Prof. A. E., Sc.D. (Pittsburgh; Toulouse) Emeritus, Elec. Eng., Harvard Univ., Cambridge, Mass.
KENNISON, L. S., A.M. (Brown) Research Asst., Princeton Univ., Princeton, N. J. *30 Murray Pl.*
KERSTEN, Asst. Prof. H. J., A.M. (Chicago) Univ. of Cincinnati, Cincinnati, Ohio. *Dept. of Math., Coll. of Eng. and Commerce.*
KEULEGAN, G. H., Ph.D. (Johns Hopkins) Asso. Physicist, Bureau of Standards, Washington, D. C. *1614 17th St. N.W.*

KEVLES, DAVID, A.B. (Pennsylvania) Teacher, Harding Jr. High School, Philadelphia, Pa. *862 N. Marshall St.*

KEYES, Mrs. JULIA ATKINSON, A.M. (California) Asst. Prof., Univ. of Arizona, Tucson, Ariz. *Box 46, University Sta.*

KICHLINE, W. L., M.S. (Lehigh) Univ. of New Hampshire, Durham, N. H.

KIEFER, Prof. E. C., M.S. (Michigan) James Millikin Univ., Decatur, Ill. *1229 W. Macon St.*

KIEFFER, NORA A., A.M. (Columbia) State Teachers Coll., Shippensburg, Pa.

KILLEBREW, Prof. C. D., M.S. (Alabama Poly. Inst.) Alabama Poly. Inst., Auburn, Ala.

KILLEN, Asso. Prof. C. G., M.S. (Louisiana) Louisiana State Normal Coll., Natchitoches, La.

KIMBALL, Asso. Prof. B. F., Ph.D. (Cornell) Univ. of New Hampshire, Durham, N. H., *Box 63.*

KIMBALL, R. S., A.M. (Brown) Supt. of Schools, North Brookfield, Mass. *43 Gilbert St.*

KIMBALL, T. C., A.M. (Princeton) Teacher, Lawrenceville School, Lawrenceville, N. J. *Box 207.*

KINDLE, Prof. J. H., A.M. (Ohio State) Eng. Coll., Univ. of Cincinnati, Cincinnati, Ohio.

KING, EULA WEEKS (Mrs. H. L.), Ph.D. (Missouri) 3233 Copelin Ave., St. Louis, Mo.

KINGERY, Prof. D. N., A.M. Macalester Coll., St. Paul, Minn. *135 Amherst St.*

KINGSTON, Prof. H. R., Ph.D. (Chicago) Math. and Astr., Univ. of Western Ontario, London, Ont., Can.

KINNEY, J. M., Ph.D. (Chicago) Head of Dept., Crane Jr. Coll., Chicago, Ill. *8058 Bennett Ave.*

KIRCHNER, Prof. W. H., B.S. (Worcester Poly. Inst.) Drawing and Descr. Geom., Univ. of Minnesota, Minneapolis, Minn. *208 Main Eng. Bldg.*

KIRKHAM, W. J., A.M. (Indiana) Instr., Oregon State Coll., Corvallis, Ore. *Dept. of Math.*

KLAUBER, L. M., A.B. (Stanford) San Diego Cons. Gas and Elec. Co., San Diego, Calif. *233 W. Juniper St.*

KLINE, Prof. J. R., Ph.D. (Pennsylvania) Univ. of Pennsylvania, Philadelphia, Pa. *529 Riverview Rd., Swarthmore, Pa.*

KLINGER, E. L., A.M. (Illinois) Instr., Purdue Univ., W. LaFayette, Ind. *126 North St.*

KNAPP, Prof. G. A., A.M. (Hamilton) Maryville College, Maryville, Tenn.

KNEBELMAN, Asst. Prof., Ph. D. (Princeton) Princeton Univ., Princeton, N. J. *9 Aiken Ave.*

KNEDLER, P. A., A.M. (Pennsylvania) Instr., Univ. of Pennsylvania, Philadelphia, Pa. *College Hall.*

KNEPPER, Prof. M. MYRTLE, A.M. (Missouri) State Teachers Coll., Cape Girardeau, Mo. *909 College Hill.*

KNIGHT, Asst. Prof. ELIZABETH E., A.M. (Illinois) State Teachers Coll., Milwaukee, Wis. 2731 N. Downer Ave.

KNIGHT, Asst. Prof. L. C., Ph.B. (Wooster) Coll. of Wooster, Wooster, Ohio.

KNISELY, ALEXANDER. Columbia City, Ind.

KNOX, Prof. J. J., S.M. (Chicago) Dakota Wesleyan Univ., Mitchell, S. D. *1219 W. University Blvd.*

KOCH, E. H. Jr., B.S. in E. E. (Pennsylvania) Chm., Applied Math., Tech. High School, Brooklyn, N.Y. *208 N. Maple Ave., East Orange, N. J.*

KOKOMOOR, Prof. F. W., Ph.D. (Michigan) Univ. of Florida, Gainesville, Fla.

KONANTZ, Prof. EMMA L., A.M. (Ohio Wesleyan) Yeu Ching Univ., Peking, China.

KOVARIK, Prof. A. F., Ph.D. (Minnesota), ScD. (Manchester) Physics, Yale Univ., New Haven, Conn. *Sloane Lab.*

KRATHWOHL, Prof. W. C., Ph.D. (Chicago) Armour Inst. of Tech., Chicago, Ill.

KRETH, DANIEL, C. E. Surveyor and Engr., Wellman, Iowa.

KRYDER, LYLAH, A.M. (Columbia) Instr., Brooklyn Coll., Brooklyn, N. Y. *66 Court St.*

KRYLOFF, Prof. NICOLAS, Doctor of Math. *honoris causa* (Kieff) Member of the Acad. of Sci. of Ukraine and of U.S.S.R. Univ. of Kieff, Kieff, Ukraine, U.S.S.R. *Box 135.*

KUHN, Prof. H. W., Ph.D. (Cornell) Ohio State Univ., Columbus, Ohio. *1179 Fairview Ave.*

KULLBACK, SOLOMON, A.M. (Columbia) 1900 F St. N.W., Washington, D. C.

KUNKEL, P. V., A.M. (Pennsylvania) Head of Dept., State Teachers Coll., Kutztown, Pa. *Box 104, Trexlertown, Pa.*

KUNTE, HELEN L., A.M. (Columbia) Instr., Hunter Coll., New York, N. Y. *Park Ave. and 68th St.*

KURZIN, W. H., M.S. (Chicago) Teacher, Crane Jr. Coll., Chicago, Ill. *1631 W. Roosevelt Rd.*

KUSNER, J. H., A.M. (Columbia) Asst., Univ. of Pennsylvania, Philadelphia, Pa. *266 S. 38th St.*

LABOCCETTA, Ing. LETTERIO, C. E. (Naples) Via S. Basilio 50, Rome (105), Italy.

LACY, Prof. CHARLOTTE M., A.M. (Chicago) West Virginia State Coll., Institute, W. Va. *Box 155.*

LADNER, Asst. Prof. A.C., A.M. (Brown) Math. and Eng., Denison Univ., Granville, Ohio. *Box 253.*

LAMBERT, W. D., A.M. (Harvard) Mathematician, U.S. Coast and Geodetic Survey, Washington, D. C.

LAMPLAND, C. O., A.M. (Indiana) Astronomer, Lowell Observ., Flagstaff, Ariz.

LANDIS, Prof. W. W., A.M. (Dickinson) Dickinson Coll., Carlisle, Pa.

LANDRY, Prof. A. E., Ph.D. (Johns Hopkins) Catholic Univ. of America, Washington, D. C. *3624 13th St., Brookland, D. C.*

LANE, Prof. E. P., Ph.D. (Chicago) Univ. of Chicago, Chicago, Ill.

LANGE, LUISE, Ph.D. (Göttingen) 5728 Blackstone Ave., Chicago, Ill.

LANGER, Prof. R. E., Ph.D. (Harvard) Univ. of Wisconsin, Madison, Wis. *521 S. Randall Ave.*

LANGMAN, HARRY, Ph.D. (Columbia) Prop., Solar Chem. Mfg. Co., Brooklyn, N. Y. *6919 Burchell St., Arverne, L. I., N. Y.*

LANHAM, D. V. Student, New River State Coll., Montgomery, W.Va. *1658 Franklin Ave., Charleston, W. Va.*

LA PAZ, Asst. Prof. LINCOLN, Ph.D. (Chicago) Ohio State Univ., Columbus, Ohio. *Dept. of Math.*

LAREW, Prof. GILLIE A., Ph.D. (Chicago) Randolph–Macon Woman's Coll., Lynchburg, Va.

LARKIN, E. J., B.S. (Cooper Union) Instr., Cooper Union, New York, N. Y. *Westbury, L. I., N. Y. Box 595.*

LARSON. Asst. Prof. OLGA, A.M. (Missouri) State Coll. for Women, Tallahassee, Fla.

LASLEY, Prof. J. W., Ph.D. (Chicago) Pure Math., Univ. of North Carolina, Chapel Hill, N. C.

LATIMER, Prof. C. G., Ph.D. (Chicago) Univ. of Kentucky, Lexington, Ky. *Dept of Math.*

LATSHAW, ELMER. 1839 N. 60th St., Philadelphia, Pa.

LATSHAW, V. V., Ph.D. (Indiana) Instr., Lehigh Univ., Bethlehem, Pa.

LAURENTINE MARIE, Sister, A.B. (Trinity Coll., Washington) Instr., Emmanuel Coll., Boston, Mass. *32 The Riverway.*

LAVES, Asso. Prof. KURT, Ph.D. (Berlin) Univ. of Chicago, Chicago, Ill. *5611 Kenwood Ave.*

LEAVENS, D. H., A.M. (Yale) Research Staff, Harvard Business School. *Soldiers Field, Boston, Mass.*

LEFEVER, RALPH, A.M. (Nebraska) Strang, Nebr.

LEFSCHETZ, Prof. SOLOMON, Ph.D. (Clark) Princeton Univ., Princeton, N. J.

LEHMAN, Prof. D. A., A.M. (Western Reserve) Goshen Coll., Goshen, Ind.

LEHMANN, C. H., A.M. (Columbia) Instr., Cooper Union Inst. of Tech., New York, N. Y. *14425-33rd Ave., Flushing, L. I., N. Y.*

LEHMER, D. H., Ph.D. (Brown) National Research Fellow, Stanford Univ., Stanford University, Calif. *Dept. of Math.*

LEHMER, Prof. D. N., Ph.D. (Chicago) Univ. of California, Berkeley, Calif. *2736 Regent St.*

LEHR, MARGUERITE, Ph.D. (Bryn Mawr) Asso., Bryn Mawr Coll., Bryn Mawr, Pa. *Low Bldgs.*

LEIB, Prof. D. D., Ph.D. (Johns Hopkins) Connecticut Coll., New London, Conn. *358 Mohegan Ave.*

LEIPER, Prof. C. L., Grad. (U. S. Naval Acad.) U. S. Naval Acad., Annapolis, Md.

LEITH, Asso. Prof. J. D., A.M. (Columbia) Univ. of North Dakota, Grand Forks, N. D.

LEMME, M. M., A.M. (Indiana) Instr., Univ. of the City of Toledo, Toledo, Ohio.

LENNAHAN, C. M. (Creighton Univ.) Observer, U. S. Weather Bureau, Washington, D. C. *1414-28lt St. N.W.*

LENNES, Prof. N. J., Ph.D. (Chicago) Univ. of Montana, Missoula, Mont.

LEONARD, Prof. H. B., Ph.D. (Colorado) Univ. of Arizona, Tucson, Ariz. *Univ. Sta., Box 24.*

LEONARD, KATHARINE, A.M. (Vermont) Head of Dept., State Teachers Coll., Moorhead, Minn. *Box 48.*

LEPESHKIN, S. A., A.M. (Columbia) Instr., Worcester Poly. Inst., Worcester, Mass.

LEPOWSKY, Mrs. FRANCES R., A.B. (Hunter) Grad. Student, Coll. of the City of New York; Substitute, James Madison High School, New York, N.Y. *229 E. 18th St., Flatbush, Brooklyn, N. Y.*

LERCH, F. S., A.B. (Lehigh) Instr., Union Coll., Schenectady, N. Y.

LESTER, CAROLINE A., A.M. (Cornell) Instr., State Coll. for Teachers, Albany, N. Y.

LESTER, Prof. O. C., Ph.D. (Yale) Dean of Grad. School and Prof. of Physics, Univ. of Colorado, Boulder, Colo. *1061 Eleventh St.*

LESTOURGEON, Asso. Prof. F. ELIZABETH, Ph.D. (Chicago) Univ. of Kentucky, Lexington, Ky. *630 Maxwelton Ct.*

LEVINE, JACK, A.B. (Univ. of Calif. at L.A.) Part-time Instr., Princeton Univ., Princeton, N. J. *32 Bank St.*
LEVY, Asst. Prof. HARRY, Ph.D. (Princeton) Univ. of Illinois, Urbana, Ill. *356 Math. Bldg.*
LEVY, Asst. Prof. SOPHIA H., Ph.D. (California) Univ. of California, Berkeley, Calif. *453 Wheeler Hall.*
LEWANDOWSKI, STEPHEN, B.S. (Marquette) Instr., Marquette Univ., Milwaukee, Wis. *1020 E. Wright St.*
LEWIS, Prof. ANNA D., Ph.D. (Carleton) Lake Erie Coll., Painesville, Ohio. *38 Paige Lane.*
LEWIS, Asst. Prof. A. J., A.M. (Denver) Univ. of Denver, Denver, Colo. *2112 S. Columbine.*
LEWIS, Asso. Prof. C. F., M.S. (K.S.A.C.) State Agric. Coll., Manhattan, Kans.
LEWIS, Asso. Prof. F. A., A.M. (Alabama) Univ. of Alabama, University, Ala.
LEWIS, Prof. FLORENCE P., Ph.D. (Johns Hopkins) Goucher Coll., Baltimore, Md. *2435 N. Charles St.*
LIBMAN, E. E., Ph.D. (Illinois) Genl. Elec. Co., Marine and Air Craft Eng. Dept., Schenectady, N. Y. *River Rd. 1, Bldg. 23, Rm. 334.*
LIEBER, LILLIAN ROSANOFF (Mrs. H. G.), Ph.D. (Clark) Teacher, Commercial High School, Brooklyn, N. Y. *258 Clinton Ave.*
LIGHT, Prof. G. H., Ph.D. (Yale) Univ. of Colorado, Boulder, Colo. *801 Base Line.*
LINARES, ENRIQUE, Jr., B.S. in E. E. (Univ. of Santa Clara) Actg. Chief Engr., Central Board of Roads, Panama City, R.P. *P.O. Box 540.*
LINDEMANN, Prof. C. A., A.M. (Bucknell) Pure Math., and Secy. of Faculty, Bucknell Univ., Lewisburg, Pa. *30 Brown St.*
LINDQUIST, Prof. THEODORE, Ph.D. (Chicago) State Normal Coll., Ypsilanti, Mich. *103 Elm St.*
LINDSEY, Prof. LOUIS, Ph.D. (Syracuse) Applied Math., Syracuse Univ., Syracuse, N. Y. *201 Scottholm Blvd.*
LINEHAN, Prof. P. H., Ph.D. (Columbia) Coll. of the City of New York, New York, N. Y. *346 Convent Ave.*
LINFIELD, Asso. Prof. B. Z., Ph.D. (Harvard) Univ. of Virginia, University, Va. *42 University Pl.*
LING, Dean G. H., Ph.D. (Columbia) Univ. of Saskatchewan, Saskatoon, Sask., Can.
LINKER, Prof. J. B., Ph.D. (Johns Hopkins) Univ. of North Carolina, Chapel Hill, N. C.
LINTON, M. ALBERT, A.M. (Haverford) Pres., The Provident Mut. Life Ins. Co., Philadelphia, Pa. *1632 Chestnut St.*
LISH, HERBERT. Draftsman, Moore Steam Turbine Corp., Wellsville, N. Y. *46 Grover St.*
LITTAUER, S. B., Ch.E. (Rensselaer), A.M. (Columbia) National Research Fellow, Harvard Univ., Cambridge, Mass. *9 Ware St.*
LITTERICK, W. S., M.S. (Brown) Instr., Peddie School, Hightstown, N. J.
LITTLE, NEIL, A.M. (Michigan) Instr., Purdue Univ., W. LaFayette, Ind. *425 Littleton St.*
LIVINGSTON, Asso. Prof. G. R., A.M. (California) State Teachers Coll., San Diego, Calif.
LOCKE, L. L., A.M. (Grove City Coll.) Teacher, Brooklyn Tr. School for Teachers, Brooklyn, N. Y. *950 St. John's Pl.*
LOCKWOOD, E. C., A.M. (Brown) Instr., American Coll., Madura, S. India. *Tallakulam P. O.*
LODWICK, DECA, Ph.B. (Iowa) Head of Dept., High School, Long Beach, Calif. *4112 Colorado St.*
LOEWEN, Prof. O. B., A.M. (Kansas) Ottawa Univ., Ottawa, Kans.
LOGSDON, Mrs. MAYME I., Ph.D. (Chicago) Asso. Prof., Univ. of Chicago, Chicago, Ill.
LONG, Asst. Prof. FLORENCE, M.S. (Illinois) Earlham Coll., Earlham, Ind.
LONG, J. K., A.B. (Washington and Jefferson) Instr., Purdue Univ., W. LaFayette, Ind. *138 Chauncey Ave.*
LONG, Asst. Prof. T. R., A.M. (Rochester) Univ. of Rochester, Rochester, N. Y. *75 Cypress St.*
LONG, Prof. W. F., A.B. (Franklin and Marshall) Math. and Astr., Franklin and Marshall Coll., Lancaster, Pa.
LONGENECKER, J. V., M.S. (Iowa) Actuary, Farmers and Bankers Life Ins. Co., Wichita, Kans. *701 Beacon Bldg.*
LONGLEY, R. W., A.M. (Harvard) Grad. Student, Harvard School of Educ., Cambridge, Mass. *82 Kirkland St.*
LONGLEY, Prof. W. R., Ph.D. (Chicago) Yale Univ., New Haven, Conn.
LOVE, Prof. C. E., Ph.D. (Michigan) Univ. of Michigan, Ann Arbor, Mich. *1915 Scottwood Ave.*
LOVETT, Pres. E. O., Ph.D. (Virginia; Leipzig) Rice Inst., Houston, Tex.
LOVITT, Prof. W. V., Ph.D. (Chicago) Colorado Coll., Colorado Springs, Colo.
LOWENSTEIN, L. L., A.B. (Cornell) Instr., Cornell Univ., Ithaca, N. Y. *White Hall.*
LOWNEY, R. E., A.M. (Mich. State Coll.) Instr., Univ. of Wisconsin, Madison, Wis. *North Hall.*

LUBBEN, Adj. Prof. R. G., Ph.D. (Texas) Univ. of Texas, Austin, Tex. *708 W. 22½ St.*
LUBIN, Asst. Prof. C. I., Ph.D. (Harvard) Coll. of Eng., Univ. of Cincinnati, Cincinnati, Ohio. *3612 Washington Ave.*
LUBY, W. A., A.M. (Kansas) Jr. Coll., Kansas City, Mo. *5411 Rockhill Rd.*
LUCK, Prof. J. J., Ph.D. (Virginia) Univ. of Virginia, University, Va. *Colonnade Club.*
LUFKIN, H. M., Ph.D. (Pennsylvania) Instr., Univ. of Pennsylvania, Philadelphia, Pa. *601 Woodcrest Ave., Ardmore, Pa.*
LUNN, Prof. A. C., Ph.D. (Chicago) Applied Math., Univ. of Chicago, Chicago, Ill.
LUTZ, Asst. Prof. JUNA M., A.M. (Chicago) Butler Univ., Indianapolis, Ind. *727 Fairfield Ave., Apt. 6.*
LYLE, G. A., M.S. (Lehigh) Instr., U. S. Naval Acad., Annapolis, Md. *112 High St.*
LYMAN, Prof. E. A., A.B. (Michigan) State Normal Coll., Ypsilanti, Mich. *308 Ellis St.*
LYON, ELLEN S. (Mrs. A. R.), A.M. (Louisville) Teacher, Jr. Coll., Campbellsville, Ky. *404 Columbia Ave.*
LYONS, Asso. Prof. W. H., A.M. (Denver) State Agric. Coll., Manhattan, Kans. *1507 Fifth Ave. N., Fort Dodge, Iowa.*
LYTLE, Asso. Prof. E. B., Ph.D. (Yale) Teaching of Math., Univ. of Illinois, Urbana, Ill. *903 S. Busey Ave.*

MACCREADIE, Asst. Prof. W. T., Ph.D. (Cornell) Bucknell Univ., Lewisburg, Pa. *1425 W. Market St.*
MACCULLOUGH, Prof. R. H., M.S. (Lafayette) Defiance Coll., Defiance, Ohio.
MACDONALD, I. J., M.S. (St. Bonaventure's) Oratory Prep. School, Summit, N. J.
MACDONALD, Prof. S. L., M.S. (Columbia) State Agric. Coll., Fort Collins, Colo.
MACDONALD, Prof. W. E., A.M. (Harvard) Lingnan Univ., Canton, China.
MACDOUGAL, H. B., M.S. (Iowa) South Dakota State Coll., Brookings, S. D. *Dept. of Math.*
MACDUFFEE, Asso. Prof. C. C., Ph.D. (Chicago) Ohio State Univ., Columbus, Ohio. *365 Oakland Park Ave.*
MACGREGOR, F. S., A.B. (Harvard) Mgr. Textbook Dept., Harper and Bros., New York, N. Y. *49 E. 33rd St.*
MACKAY, ROY, A.B. (New Mexico) Grad. Student, Univ. of New Mexico; Teacher, High School, Albuquerque, N. M. *917 E. Grand Ave.*
MACKIE, Asso. Prof. E. L., Ph.D. (Chicago) Univ. of North Carolina, Chapel Hill, N. C. *702 Gimghoul Rd.*
MACLEAN, Lieut.-Col. N. B., Ph.D. (Chicago) Prof., Applied Math., McGill Univ., Montreal, P.Q., Can.
MACMILLAN, Prof. W. D., Ph.D. (Chicago) Astr., Univ. of Chicago, Chicago, Ill.
MAC NEISH, Asso. Prof. H. F., Ph.D. (Chicago) Brooklyn Coll., Brooklyn, N.Y. *Scarsdale, N. Y.*
MACNUTT, BARRY, M.S. (Lehigh) 643 Washington St., Gloucester, Mass.
MCALISTER, Prof. E. H., A.M. (Oregon) Mech. and Astr., Univ. of Oregon, Eugene, Ore. *334 Pearl St.*
MCCAIN, Prof. GERTRUDE I., Ph.D. (Indiana) Marymount Coll., Salina, Kans.
MCCARTHY, E. D., A.B. (Cornell) Instr., Eng. Coll., Univ. of Detroit, Detroit, Mich.
MCCARTY, A. L., A.M. (California) Head of Dept., Lowell High School, Berkeley, Calif. *2137 Parker St.*
MCCLELLAN, ADA A., B.S. (Chicago) 313 N. New Hampshire Ave., Los Angeles, Calif.
MCCLENON, Prof. R. B., Ph.D. (Yale) Grinnell Coll., Grinnell, Iowa. *1105 Park St.*
MCCORMICK, Prof. CLARENCE, A.M. (Clark) State Teachers Coll., Weatherford, Okla.
MCCORMICK, W. W., M.S. (Michigan) Instr., Math. and Physics, Geneva Coll., Beaver Falls, Pa. *On leave 1931–32, Univ. of Michigan, Ann Arbor, Mich.*
MCCOY, Prof. DOROTHY, Ph.D. (Iowa) Belhaven Coll., Jackson, Miss.
MCCOY, M. HELEN, A.M. (Illinois) Address unknown.
MCCOY, Asst. Prof. N. H., Ph.D. (Iowa) Smith Coll., Northampton, Mass. *29 Kensington Ave.*
MCCUE, Prof. M. J., C. E., M.S. (Notre Dame) Coll. of Eng., Univ. of Notre Dame, Notre Dame, Ind. *130 Fremont St., Woodstock, Ill.*
MCDILL, Prof. R. M., A.M. (Indiana) Hastings Coll., Hastings, Nebr. *129 E. 7th St.*
MCDONALD, EMMA WHITON (Mrs. J. H.), A.M. (California) Hotel Claremont, Berkeley, Calif.
MCDONALD, JANET, A.M. (Tulane) Teacher, Mississippi Synodical Coll., Holly Springs, Miss. *Box 244.*
MCDONOUGH, D. L., A.M. (Pennsylvania) Teacher, Overbrook High School; Drexel Inst., Philadelphia, Pa. *18 Sunshine Rd., Upper Darby, Pa.*
MCDOUGLE, EDITH A., A.B. (Delaware) Instr., Women's Coll., Univ. of Delaware, Newark, Del.

McEWEN, Prof. G. F., Ph.D. (Stanford) Oceanographer, Scripps Inst., Univ. of California. *Box 68, La Jolla, Calif.*

McEWEN, W. H., Ph.D. (Minnesota) Mount Allison Univ., Sackville, N. B., Can. *Box 475.*

McFARLAN, Asst. Prof. L. H., Ph.D. (Missouri) Univ. of Washington, Seattle, Wash.

McFARLAND, Asst. Prof. DORA, A.M. (Oklahoma) Univ. of Oklahoma, Norman, Okla.

McFARLAND, ELSIE J., Ph.D. (California) 122 E. Jefferson Ave., Kirkwood, Mo.

McGAVOCK, Asso. Prof. MARTHA P., A.M. (Chicago) Rockford Coll., Rockford, Ill.

McGAW, Prof. F. M., A.M. (Phila. City Coll.) Math. and Eng. Drawing, Cornell Coll., Mt. Vernon, Iowa.

McGIFFERT, Prof. JAMES, Ph.D. (Columbia) Pure Math., Grad. Dept., Rensselaer Poly. Inst., Troy, N. Y. *169 Eighth St.*

McGINLEY, MARGARET F., A.M. (Colorado) Teacher, Denver Schools, Denver, Colo. *1601 E. Mississippi Ave.*

McKELVEY, Asso. Prof. J. V., Ph.D. (Cornell) Iowa State Coll., Ames, Iowa. *2117 Graeber St.*

McKELVEY, MARTHA M. (Mrs. J. V.), M.S. (Iowa) Instr., Iowa State Coll., Ames, Iowa. *2117 Graeber St.*

McLAUGHLIN, Prof. J. A., M.S. (Colgate) Head of Dept., St. Bonaventure's Coll., Allegany, N. Y.

McMASTER, A. S., M.S. in C.E. (Colorado) Instr., Eng. Math., Univ. of Colorado, Boulder, Colo. *Coll. of Engineering.*

McMILLAN, MARY B., A.M. (Wisconsin) 1341 Third St. S., Wisconsin Rapids, Wis.

McNATT, J. Q. Div. Engr., Colorado Fuel and Iron Co., Canon City, Colo. *910 Glenwood Ave.*

McNELLY, Sister MARY OF THE PRESENTATION, A.M. (Catholic Univ.) Prof., Our Lady of the Lake Coll., San Antonio, Tex.

McSHANE, E. J., Ph.D. (Chicago) National Research Fellow, Univ. of Chicago, Chicago, Ill. *Eckhart Hall.*

McSWEENY, Prof. A. A., A.M. (Montana) Head of Dept., John Tarleton Agric. Coll., Stephenville, Tex.

MADDOX, Prof. A. C., A.M. (Columbia) State Normal Coll., Natchitoches, La. *405 New Second St.*

MAGEE, S. R. Kinderhook, Columbia Co., N. Y.

MAIDEN, W. M., A.M. (Virginia) Washington Square Coll., New York Univ., New York, N. Y. *Washington Sq. E.*

MAIZLISH, Asso. Prof. ISRAEL, Ph.D. (Minnesota) Physics, Centenary Coll., Shreveport, La.

MAJELLA, Brother, A.M. (Catholic Univ.) St. John's Prep. School, Danvers, Mass.

MALE, Asst. Prof. C. T., M.C.E. (Union) Union Coll., Schenectady, N. Y. *Niskayuna, Schenec. Co., N. Y.*

MALLORY, Asso. Prof. V. S., A.M. (Columbia) State Teachers Coll., Montclair, N. J.

MANCHESTER, Prof. R. E., A.M. (Michigan) Head of Dept., and Dean of Men, Kent State Coll., Kent, Ohio.

MANEY, Prof. C. A., M.S. (Chicago) Transylvania Coll., Lexington, Ky. *670 N. Broadway.*

MANGOLD, Prof. M. CECILIA, Ph.D. (Catholic Univ.) Trinity Coll., Washington, D. C.

MANNING, Asst. Prof. F. L., M.S. (Rutgers) Ursinus Coll., Collegeville, Pa.

MANNING, Dr. H. M. U. S. Public Health Service, c/o American Consulate, Rotterdam, Holland.

MANNING, Asso. Prof. H. P., Ph.D. (Johns Hopkins) Emeritus, Brown Univ., Providence, R. I. *106 Carrington Ave., E. Side Sta.*

MANSON, Prof. E. S., M.S. (Mass. Inst. of Tech.) Astr., Ohio State Univ., Columbus, Ohio.

MANY, Asst. Prof. ANNA E., A.M. (Tulane) Counselor to Women, Sophie Newcomb Coll., New Orleans, La.

MARCH, Asst. Prof. G. E., B.S. (S. Dak. School of Mines) South Dakota State School of Mines, Rapid City, S. D. *1216 Fulton St.*

MARKOWITZ, MAX. Student, Brooklyn Coll., Brooklyn, N. Y. *2037-71st. St.*

MARM, Prof. ANNA, A.M. (Kansas) Bethany Coll., Lindsborg, Kans. *741 N. 2nd St.*

MARRIOTT, Prof. R. W., Ph.D. (Pennsylvania) Swarthmore Coll., Swarthmore, Pa. *213 Lafayette Ave.*

MARSHALL, Prof. WILLIAM, Ph.D. (Zürich) Head of Dept., Purdue Univ., LaFayette, Ind. *1017 State St.*

MARTIN, Prof. A. W., Ph.D. (Chicago) Coll. of Puget Sound, Tacoma, Wash. *3209 N. 15th St.*

MARTIN, Prof. EMILIE N., Ph.D. (Bryn Mawr) Mount Holyoke Coll., South Hadley, Mass.

MARTIN, MARY C., B.S. (Knox) Teacher, High School, Freeport, Ill. *831 W. Stephenson St.*

MARTYN, W. J., M.A. (New Zealand) Mathematical Master, Otago Boys High School, Dunedin, New Zealand.

MARY JOAN, SISTER, A.B. (St. Catherine's Coll.) Teacher, St. Catherine's High School, Racine, Wis. *1209 Park Ave.*
MASON, Prof. T. E., Ph.D. (Indiana) Purdue Univ., LaFayette, Ind. *103 Waldron St.*
MASON, Asst. Prof. W. E., M.E. (Michigan) Applied Math., Univ. of California at Los Angeles, Los Angeles, Calif.
MATHESON, Prof. JOHN, M.A. (Queen's) Queen's Univ., Kingston, Ont., Can.
MATHEWS, JANE H., B.S. (Columbia) Teacher, Peabody High School, Pittsburgh, Pa. *Cathedral Mansions, Ellsworth Ave. E. E.*
MATHEWSON, Asst. Prof. L. C., Ph.D. (Illinois) Dartmouth Coll., Hanover, N. H.
MATHIAS, FLORENTINA, A.M. (Ohio State) Teacher, High School, Chillicothe, Ohio. *38 Ewing St.*
MATHIAS, H. R., A.M. (Indiana) Instr., Bowling Green State Coll., Bowling Green, Ohio. *303 N. Prospect St.*
MATHIS, BUENA C., A.B. (Kentucky) Grad. Asst., Univ. of Kentucky, Lexington, Ky. *R.F.D. 9.*
MATTESON, Asso. Prof. JANE L. Michigan State Normal Coll., Ypsilanti, Mich. *318 W. Cross St.*
MAURUS, Prof. E. J., M.S. (Notre Dame) Univ. of Notre Dame, Notre Dame, Ind. *L.B. 75.*
MAY, LIDA B., A.M. (Texas) Teacher, High School, Borger, Tex. *Box 1403.*
MAYER, JOANNA I., Ph.D. (Marquette) 234 S. Vermont St., Sedalia, Mo.
MEADE, MARY E., A.M. (Virginia) Instr. and Acting Dean of Women, Martin Coll., Pulaski, Tenn.
MEACHAM, Prof. E. D., Ph.D. (Chicago) Univ. of Oklahoma, Norman, Okla. *712 Lindsay Ave.*
MEARS, Asst. Prof. FLORENCE M., Ph.D. (Cornell) George Washington Univ., Washington, D. C.
MEBANE, Asst. Prof. W. N., Jr., A.M. (Cornell) Davidson Coll., Davidson, N. C. *Box 274.*
MEDER, Asst. Prof. A. E., A.M. (Columbia) New Jersey Coll. for Women, New Brunswick, N. J.
MEEK, KATE M. High School, Pasadena, Calif. *919 E. California St.*
MELVILLE, Asso. Prof. C. E., A.B. (Northwestern) Math. and Registrar, Clark Univ., Worcester, Mass.
MENDENHALL, Pres. W. O., Ph.D. (Michigan) Friends Univ., Wichita, Kans.
MENKE, Asst. Prof. H. E., A.M. (Ohio State) Otterbein Coll., Westerville, Ohio. *124 W. Home St.*
MENSENKAMP, L. E., A.M. (Illinois) Instr., High School, Freeport, Ill. *808 W. American St.*
MENUET, Asso. Prof. R. L., B.E. (Tulane) Tulane Univ., New Orleans, La.
MERCEDES, Sister M., M.S. (Notre Dame) Instr., Mary Manse Coll., Toledo, Ohio.
MERGENDAHL, Asst. Prof. T. E., M.S. (Tufts) Math. and Registrar, Tufts Coll., Tufts College, Mass. *128 Professors Row.*
MERRILL, Prof. A. S., Ph.D. (Chicago) Univ. of Montana, Missoula, Mont. *541 Beckwith Ave.*
MERRILL, Prof. HELEN A., Ph.D. (Yale) Wellesley Coll., Wellesley, Mass.
MERRILL, J. E., Ph.D. (Princeton) Univ. of Illinois Observ., Urbana, Ill.
MERRIMAN, Asst. Prof. G. M., Ph.D. (Cincinnati) Pure Math., Univ. of Cincinnati, Cincinnati, Ohio.
MERRISS, A. A. 913 East 23rd St. N., Portland, Ore.
MESSICK, Asso. Prof. C. A., Ph.D. (Chicago) Lincoln Memorial Univ., Harrogate, Tenn.
MESSICK, Prof. J. F., Ph.D. (Johns Hopkins) Emory Univ., Emory University, Ga.
MEYER, Prof. H. A., Ph.D. (Iowa) Hanover Coll., Hanover, Ind. *Box 3.*
MEYER, Prof. J. B., M.S. (Purdue) Head of Dept., State Teachers Coll., Valley City, N. D. *814 Fifth Ave.*
MEYER, Rev. J. H. Loretto House, Hot Springs, N. C.
MICHAL, Asso. Prof. A. D., Ph.D. (Rice) California Inst. of Tech., Pasadena, Calif.
MICKELSON, Prof. E. L., Ph.D. (Minnesota) Math. and Physics, State Teachers Coll., Silver City, N. Mex. *503 Kelly St.*
MICKLE, M. KATHERINE, A.B. (Alabama) Roanoke, Ala.
MIDDLEMISS, Asst. Prof. R. R., M.S. (Colorado) Washington Univ., St. Louis, Mo.
MIKAMI, YOSHIO. Research Assoc., Imperial Acad., Tokyo, Japan. *7 Daini Mejiro Bunkamura, 1321 Shimo Ochiai.*
MIKESH, J. S. Lawrenceville School, Lawrenceville, N. J.
MILES, Asso. Prof. E. J., Ph.D. (Chicago) Yale Univ., New Haven, Conn. *87 Marvel Rd.*
MILES, H. J., Ph.D. (California) Instr., Univ. of Illinois, Urbana, Ill. *369 Math. Bldg.*
MILLER, A. L., Ph.D. (Harvard) 25 Clinton Road, Brookline 46, Mass.
MILLER, Prof. E. B., A.M. (Chicago) Illinois Coll., Jacksonville, Ill. *1205 W. College Ave.*
MILLER, F. H., M.S. (Cornell) Instr., Columbia Univ., New York, N. Y. *45 Sickles St.*

MILLER, Prof. G. A., Ph.D. (Cumberland) Univ. of Illinois, Urbana, Ill. *1203 W. Illinois St.*
MILLER, G. T., M.S. (Iowa State Coll.) Instr., Purdue Univ., LaFayette, Ind. *222 Harrison St.*
MILLER, Prof. I. L., A.M. (Indiana) South Dakota State Coll., Brookings, S. D. *811 12th Ave.*
MILLER, Prof. J. A., Ph.D. (Chicago) Astr., Swarthmore Coll., Swarthmore, Pa.
MILLER, Prof. J. S., Sc.D. (Virginia) Emory and Henry Coll., Emory, Va.
MILLER, Prof. NORMAN, Ph.D. (Harvard) Queen's Univ., Kingston, Ont., Can.
MILLER, W. I., A.M. (Bucknell) Fellow, Univ. of Pittsburgh, Pittsburgh, Pa. *722 Broad St., Sewickley, Pa.*
MILLER, Asst. Prof. W. M., Ph.D. (Illinois) Tufts Coll., Medford, Mass. *37 Chetwynd Rd., W. Somerville, Mass.*
MILLIKAN, Asst. Prof. C. B., Ph.D. (Calif. Inst. of Tech.) Grad. School of Aeronautics, California Inst. of Tech, Pasadena, Calif.
MILLINGTON, Asst. Prof. H. G., C.E. (Rensselaer) Coll. of Eng., Univ. of Vermont, Burlington, Vt. *224 Plattsburg Ave.*
MILLS, Prof. C. N., A.M. (Indiana) Illinois State Normal Univ., Normal, Ill. *602 N. School St.*
MILLS, VICENTE. Chief Surveyor, Bureau of Lands, Manila, P.I. *P. O. Box 2442.*
MILNE, Asst. Prof. T. H., M.A. (Toronto) Univ. of Manitoba, Winnipeg, Man., Can.
MILNE, Prof. W. E., Ph.D. (Harvard) Univ. of Oregon, Eugene, Ore. *1862 Kincaid St.*
MIRICK, G. R., A.M. (Michigan) Teacher, Lincoln School., Teachers Coll., New York, N. Y. *425 W. 123 St.*
MISER, NELLIE P. (Mrs. W. L.), A.B. (Huron Coll.) Teacher, Ward-Belmont School, Nashville, Tenn. *1715 Ashwood Ave.*
MISER, Prof. W. L., Ph.D. (Chicago) Vanderbilt Univ., Nashville, Tenn. *1715 Ashwood Ave.*
MISH, A. F., A.B. (West Virginia) Instr., High School, Grafton, W. Va. *Inwood, Berkeley Co., W. Va.*
MITCHELL, Asst. Prof. A. K., Ph.D. (Johns Hopkins) Trinity Coll., Hartford, Conn. *149 N. Whitney St.*
MITCHELL, Prof. B. E., Ph.D. (Columbia) Millsaps Coll., Jackson, Miss.
MITCHELL, Mrs. DECIMA E., M.A. (Alberta) 600 W. 32nd St., Austin, Tex.
MITCHELL, Prof. H. H., Ph.D. (Princeton) Univ. of Pennsylvania, Philadelphia, Pa. *College Hall.*
MITCHELL, Prof. U. G., Ph.D. (Princeton) Head of Dept., Univ. of Kansas, Lawrence, Kans. *1313 Massachusetts Ave.*
MITRA, Prof. N. B., M.A. (Calcutta Univ.) Ewing Christian Coll., Allahabad City, U.P., India.
MIZE, CLARA P., M.S. (Chicago) Head of Dept., Virginia Intermont Coll., Bristol, Va.
MODE, Prof. E. B., A.M. (Harvard) Boston Univ., Boston, Mass. *688 Boylston St.*
MOENCH, Prof. L. W., A.B. (Macalester) German and Religion, Prin. of Acad., St. Paul Luther Coll., St. Paul, Minn.
MOLINA, E. C. Tel. Engr., Amer. Tel. and Tel. Co. New York, N. Y. *195 Broadway.*
MONASTERIO, Prof. J. O., C.E. (Chapultepec Mil. Acad.) Math. and Physics, Loyola Univ., New Orleans, La.
MONTAGUE, HARRIET F., A.M. (Buffalo) Instr., Univ. of Buffalo, Buffalo, N. Y. *3425 Main St.*
MOODY, ETHEL I., Ph.D. (Cornell) Instr., Sweet Briar Coll., Sweet Briar, Va.
MOODY, Prof. W. A., A.M. (Bowdoin) Emeritus, Bowdoin Coll., Brunswick, Me. *60 Federal St.*
MOORE, Asso. Prof. C. L. E., Ph.D. (Cornell) Mass. Inst. of Tech., Cambridge, Mass.
MOORE, Prof. C. N., Ph.D. (Harvard) Univ. of Cincinnati, Cincinnati, Ohio. *219 Woolper Ave.*
MOORE, Prof. E. H., Ph.D. (Yale) Univ. of Chicago, Chicago, Ill.
MOORE, Asso. Prof. F. C., A.B. (Dartmouth) Mass. Agric. Coll., Amherst, Mass.
MOORE, G. E., M.S. (Illinois) Asst., Univ. of Illinois, Urbana, Ill. *712 W. Arlington Ct., Champaign, Ill.*
MOORE, Asst. Prof. L. T., Ph.D. (Johns Hopkins) Brooklyn Coll., Brooklyn, N. Y. *59 Livingston St.*
MOORE, Prof. R. L., Ph.D. (Chicago) Pure Math., Univ. of Texas, Austin, Tex.
MOORE, Asst. Prof. T. W., Ph.D. (Yale) Indiana Univ., Bloomington, Ind. *Dept. of Math.*
MOORE, Prof. W. A., A.M. (Chicago) Birmingham Southern Coll., Birmingham, Ala.
MOORE, Asso. Prof. W. L., Ph.D. (Illinois) Univ. of Louisville, Louisville, Ky. *4521 S. 2nd St.*
MOOTS, E. E., Ph.D. (Iowa) Chm., Math. and Eng., Cornell Coll., Mt. Vernon, Iowa. *824 Summit Ave.*

MOREHOUSE, T. C. Mgr., College Dept., The Macmillan Co., New York, N.Y. *60 Fifth Ave.*
MORENO, Prof. H. C., Ph.D. (Clark) Applied Math., Stanford Univ., Stanford University, Calif. *684 Mirada Ave.*
MORENUS, Prof. EUGENIE M., Ph.D. (Columbia) Sweet Briar Coll., Sweet Briar, Va.
MORGAN, F. M., Ph.D. (Cornell) Dir., Clark School, Hanover, N. H.
MORGAN, W. D. 740 Curfew Ave., St. Paul, Minn.
MORIARTY, M. M. S., A.B. (Holy Cross) Emeritus, High School, Holyoke, Mass. *Petersham, Mass.*
MORITZ, Prof. R. E., Ph.D. (Strassburg) Univ. of Washington, Seattle, Wash.
MORLEY, Prof. R. K., Ph.D. (Clark) Worcester Poly. Inst., Worcester, Mass. *43 Laconia Rd.*
MORRILL, W. K., Ph.D. (Johns Hopkins) Instr., Johns Hopkins Univ., Baltimore, Md. *5203 Gwynn Oak Ave.*
MORRIS, Prof. C. C., A.M. (Harvard) Ohio State Univ., Columbus, Ohio.
MORRIS, Prof. F. R., Ph.D. (California) State Teachers Coll., Fresno, Calif.
MORRIS, Asst. Prof. MAX, Ph.D. (Chicago) Case School of Appl. Sc., Cleveland, Ohio.
MORRIS, Prof. RICHARD, Ph.D. (Cornell) Rutgers Univ., New Brunswick, N. J. *12 Johnson St.*
MORRIS, Prof. S. S., M.S. (West Virginia) Broaddus Coll., Philippi, W. Va.
MORROW, E. B., A.B. (Princeton) Headmaster, Gilman Country School, Roland Park, Md.
MORSE, Prof. D. S., Ph.D. (Cornell) Union Coll., Schenectady, N. Y. *1372 Nott St.*
MORSE, Prof. MARSTON, Ph.D. (Harvard) Harvard Univ., Cambridge, Mass. *1737 Cambridge St.*
MORSE, Prof. W. P., A.M. (Maine) Ricker Jr. Coll., Houlton, Me.
MORTON, Prof. A. B., A.M. (Brown) Pure Math., Georgia School of Tech., Atlanta, Ga.
MORTON, NELLIE C., A.B. (Brown) Asst. in Astr., Wellesley Coll., Wellesley, Mass.
MOSKOVITZ, David, M.S. (Carnegie Inst. of Tech.) Brown Univ., Providence, R. I.
MOSSMAN, Asst. Prof. THIRZA A., A.M. (Chicago) State Agric. Coll., Manhattan, Kans.
MOULTON, Dean E. J., Ph.D. (Chicago) Northwestern Univ., Evanston, Ill. *1114 Colfax St.*
MOULTON, F. R., Ph.D. (Chicago) Dir., Utilities Power and Light Corp., Chicago, Ill. *327 S. LaSalle St.*
MOURAD, Lieut. Commander SALIH (Turkish Navy; retired) Prof. of Physics, Govt. Eng. Coll; Appl. Math., Robert Coll., Constantinople, Turkey. *Robert College, Bebek.*
MOYLE, K. E., A.M. (Bucknell) Teacher, Moses Brown School, Providence, R. I.
MUEHLMAN, Rev. PAUL, A.M. (St. Louis Univ.) St. Louis Univ., St. Louis, Mo. *221 Grand Blvd.*
MUIR, Sir THOMAS, D.Sc. (Univ. of Cape Town) Late Supt.-Genl. of Educ., Cape Colony. *Elmcote, Sandown Rd., Rondebosch, S. Africa.*
MULLEMEISTER, Asst. Prof. HERMANCE, Ph.D. (Utrecht, Holland) Univ. of Washington, Seattle, Wash. *Dept. of Math.*
MULLEN, Mrs. SELAH W., B.S. (Michigan) Teacher, North East High School, Detroit, Mich. *286 E. Grand Blvd.*
MULLER, JESSIE J. (Mrs. HERMANN J.), Ph.D. (Illinois) Univ. of Texas, Austin, Tex.
MULLINGS, M. E., Ph.D. (Cincinnati) Instr., Eng. Math., Univ. of Cincinnati, Cincinnati, Ohio. *Dept of Math.*
MULLINS, Prof. G. W., Ph.D. (Columbia) Barnard Coll., Columbia Univ., New York, N. Y. *Barnard Coll., 119th St. and Broadway.*
MUNDHJELD, SIGURD, A.B. (Concordia, Moorhead, Minn.) Instr., Waldorf Coll., Forest City, Iowa.
MUNROE, FLORENCE L., A.B. (Wellesley) Teacher, High School, Northampton, Mass. *5 Franklin St.*
MURFEE, Col. W. L., A.M. (Virginia) Pres., Marion Inst., Marion, Ala.
MURNAGHAN, Prof. F. D., Ph.D. (Johns Hopkins) Johns Hopkins Univ., Baltimore, Md.
MURRAY, Asso. Prof. C. A., A.M. (Texas) State Teachers Coll., Canyon, Tex. *On leave 1931–32, Univ. of Texas, Austin, Tex.*
MURRAY, Prof. D. A., Ph.D. (Johns Hopkins) Applied Math., McGill Univ., Montreal, P. Q., Can. *3653 University St.*
MURRAY, F. H., Ph.D. (Harvard) Address unknown.
MURRAY, G. H., B.S. in Bus. Adm. (Missouri) 2934 Victor St., Kansas City, Mo.
MURTO, Miss ARRIA, M.S. (Chicago) Teacher, High School, Carthage, Mo. *914 Howard Ave.*
MUSSELMAN, Prof. J. R., Ph.D. (Johns Hopkins) Western Reserve Univ., Cleveland, Ohio.
MYERS, Prof. H. S., A.M. (Chicago) Southwestern Coll., Winfield, Kans. *1501 E. 3rd Ave.*

NASH, F. P., A.M. (Columbia) Teacher, Groton School, Groton, Mass.
NASSAU, Prof. J. J., Ph.D. (Syracuse) Astr., Case School of Appl. Sci., Cleveland, Ohio.

NEELLEY, Prof. J. H., Ph.D. (Yale) Carnegie Inst. of Tech., Pittsburgh, Pa. *300 Broadmoor Ave., Sunset Hills, Mt. Lebanon, Pa.*
NEFF, Prof. I. F., M.S. (Drake; Chicago) Drake Univ., Des Moines, Iowa. *2801 Brattleboro Ave.*
NEIKIRK, Asst. Prof. L. I., Ph.D. (Pennsylvania) Univ. of Washington, Seattle, Wash. *4723-21st. Ave. N.E.*
NELSON, Prof. A. L., Ph.D. (Chicago) Coll. of the City of Detroit, Detroit, Mich.
NELSON, Asso. Prof. C. A., Ph.D. (Chicago) New Jersey Coll. for Women, Rutgers Univ., New Brunswick, N. J.
NELSON, W. A., A.M. (Texas) Teacher, Jr. Coll., Tyler, Tex. *Box 676.*
NELSON, Asso. Prof. W. K., M.S.; E.E. (Colorado) Eng. Math., Univ. of Colorado, Boulder, Colo. *925 Grandview Ave.*
NESS, MARIE M., A.M. (Minnesota) Research Assoc., Univ. of Minnesota, Minneapolis, Minn. *2530 Dupont Ave. S.*
NEUBAUER, GRETA, A.M. (Wyoming) Instr., Univ. of Wyoming, Laramie, Wyo. *Ivinson Hall.*
NEWELL, M. J., A.M. (Michigan) Teacher, High School, Evanston, Ill. *2226 Hartzell St.*
NEWLIN, Asst. Prof. R. L., M.S. (Chicago) Ohio Wesleyan Univ., Delaware, Ohio. *163 N. Sandusky St.*
NEWSOM, Prof. C. V., Ph.D. (Michigan) Univ. of New Mexico, Albuquerque, N. Mex.
NEWSON, Prof. MARY W., Ph.D. (Göttingen) Eureka Coll., Eureka, Ill.
NEWTON, F. E., Ph.B. (Yale) Instr., Phillips Acad., Andover, Mass. *9 Salem St.*
NEWTON, Prof. G. A., A.M. (Trinity Univ.) Head of Dept., Trinity Univ., Waxahachie, Tex.
NICHOLS, G. D., A.M. (Nebraska) Univ. of Arkansas, Fayetteville, Ark. *Dept. of Math.*
NICHOLS, Prof. I. C., Ph.D. (Michigan) Applied Math., Louisiana State Univ., Baton Rouge, La.
NICKOL, Prof. J. P., Ph.D. (Fribourg) Physics, St. Bonaventure's Coll., St. Bonaventure, N. Y.
NICOLET, JUSTIN, C.E. 1849 Belle Plaine Ave., Chicago, Ill.
NIXON, J. C., M.S. (Chicago) 430 Diversey Parkway, Chicago, Ill.
NOBLE, Prof. C. A., Ph.D. (Göttingen) Univ. of California, Berkeley, Calif. *2224 Piedmont Ave.*
NORBERT, Brother, M.S. (Notre Dame) Instr., St. Edwards Univ., Austin, Tex.
NORDGAARD, Prof. M. A., Ph.D. (Columbia) Wagner Coll., Staten Island, N. Y. *Grymes Hill.*
NYBERG, J. A., M.S. (Chicago) Instr., Hyde Park High School, Chicago, Ill. *7753 East End Ave., Windsor Park Sta.*
NYSWANDER, Asst. Prof. J. A., Ph.D. (Chicago) Univ. of Michigan, Ann Arbor, Mich.

OAKLEY, Asst. Prof. C. O., Ph.D. (Illinois) Brown Univ., Providence, R. I.
O'DONNELL, G. A., A.M. (Woodstock; Georgetown) Grad. Student, St. Louis Univ., St. Louis, Mo. *Grand and Pine Blvds.*
OERGEL, C. T., B.S. in M.E. (Penna. State Coll.) Student Engr., Genl. Elec. Co., Schenectady, N. Y. *1054 Glenwood Blvd.*
OGLESBY, Prof. E. J., A.M. (Virginia) Eng. Math., Univ. of Virginia, University, Va. *P. O. Box 1032.*
OKEAN, HARRY, B.S. (Alfred) Address unknown.
OLDENBURGER, RUFUS, M.S. (Chicago) Instr., Case School of Appl. Sc., Cleveland, Ohio. *Main 67.*
OLDHAM, Asst. Prof. MABEL R., A.M. (Texas) State Coll. for Women, Denton, Tex. *Box 895, C.I.A. Sta.*
OLDS, Asso. Prof. E. G., Ph.D. (Pittsburgh) Carnegie Inst. of Tech., Pittsburgh, Pa. *1424 Barnsdale St.*
OLLIVIER, ARTHUR, M.S. (Iowa) Instr., State Agric Coll., Manhattan, Kans. *Dept. of Math.*
OLSON, EMMA J., A.M. (Chicago) 2218 S. St. Aubin St., Morningside, Sioux City, Iowa.
OLSON, Asst. Prof. H. L., Ph.D. (Chicago) Michigan State Coll., East Lansing, Mich. *544 Forest Ave.*
OPP, J. E., A.M. (Nebraska) Supt. City Schools, Burwell, Nebr.
O'QUINN, R. L., A.B. (Louisiana) Instr., Louisiana State Univ., Baton Rouge, La.
ORANGE, WILLIAM, A.M. (California) Chm., Math. Dept., Jr. Coll., Los Angeles, Calif. *855 N. Vermont Ave.*
ORE, Prof. OYSTEIN, Ph.D. (Yale) Yale Univ., New Haven, Conn.
ORR, EUNICE C., A.M. (Indiana) Teacher, High School, Arcadia, Ind. *Scircleville, Ind.*
OSBORN, Prof. JESSE, Ph.D. (Cornell) Harris Teachers Coll., St. Louis, Mo. *3239 Lafayette Ave.*
OSGOOD, Prof. W. F., Ph.D. (Erlangen) Harvard Univ., Cambridge, Mass. *74 Avon Hill St.*

O'SHAUGHNESSY, Prof. LOUIS, Ph.D. (Pennsylvania) Applied Math., Virginia Poly. Inst., Blacksburg, Va. *Box 177.*
O'TOOLE, A. L., Ph.D. (Michigan) National Research Fellow, Univ. of Minnesota, Minneapolis, Minn. *1109 Sixth St. S.E.*
OTT, Prof. W. P., Ph.D. (Chicago) Univ. of Alabama, University, Ala.
OVERMAN, J. R., Ph.D. (Michigan) Head of Dept., State Coll., Bowling Green, Ohio.
OWENS, Prof. F. W., Ph.D. (Chicago) Head of Dept., Pennsylvania State Coll., State College, Pa. *526 E. Foster Ave.*
OWENS, HELEN B. (Mrs. F. W.), Ph.D. (Cornell) 526 E. Foster Ave., State College, Pa.
OXSHEER, Asso. Prof. LELA, A.M. (Teachers Coll., Columbia) Stephen F. Austin Teachers Coll., Nacogdoches, Tex. *516 North St.*

PAASWELL, GEORGE, C.E. (Cornell) Consulting Engr., New York, N. Y. *1950 Andrews Ave., Bronx.*
PACKER, MARGARET C., A.M. (Brown) Bell Telephone Labs., New York, N. Y. *463 West St. Room 957.*
PALMIÉ, Prof. ANNA H., Ph.B. (Cornell) Emeritus, Coll. for Women, Western Reserve Univ., Cleveland, Ohio. *Ormond Beach, Fla.*
PARADISO, L. J. A.M. (Ohio State) Cornell Univ., Ithaca, N. Y., *129 Linden Ave.*
PARK, Prof. R. S., Ph.D. (Kentucky) Eastern Teachers Coll., Richmond, Ky. *213 Burnam Ct.*
PARKER, Prof. W. P., M.A. (Emory Univ.) Union Christian Coll., Pyengyang, Korea.
PARKINSON, Asso. Prof. G. A., Ph.D. (Wisconsin) Univ. of Wisconsin, Extension Div., Milwaukee, Wis. *623 W. State St.*
PARSON, S. F. Head of Dept., Northern Illinois State Teachers Coll., De Kalb, Ill. *305 College Ave.*
PARTRIDGE, E. A., Ph.D. (Pennsylvania) Science, West Phila. High School for Boys, Philadelphia, Pa. *48th and Walnut Sts.*
PASSANO, Asso. Prof. L. M., A.B. (Johns Hopkins) Mass. Inst. of Tech., Cambridge, Mass.
PATTEN, Prof. W. E., C.E. (Cornell) 401 Conklin Ave., Binghamton, N. Y.
PATTERSON, Asso. Prof. B. C., Ph.D. (Johns Hopkins) Hamilton Coll., Clinton, N. Y. *College Hill.*
PATTILLO, Dean N. A., Ph.D. (Johns Hopkins) Randolph-Macon Women's Coll., Lynchburg, Va.
PATTON, BESS, M.S. (Chicago) Teacher, Girls' High School, Atlanta, Ga. *1585 N. Decatur Rd. N.E.*
PAULA, Sister MARY, M.S. (Notre Dame) Prof., Marygrove Coll., Detroit, Mich.
PAULINUS, Brother, A.B. (Mt. St. Joseph) Instr., St. Xavier High School, Louisville, Ky.
PAXTON, Asso. Prof. E. K., A.M. (Columbia) Washington and Lee Univ., Lexington, Va.
PAXTON, MARY S., A.M. (Indiana) Teacher, South Side High School, Fort Wayne, Ind. *125 E. Branning Ave.*
PAYNE, C. K., M.B.A. (New York Univ.) Instr., Washington Square Coll., New York, N. Y. *100 Washington Sq. E.*
PECK, W. D., A.B. (Lebanon Valley) Head of Dept., Asheville School for Boys, Asheville, N. C.
PECKHAM, Asso. Prof. ANNA B., A.M. (Denison) Denison Univ., Granville, Ohio.
PEDERSEN, Asso. Prof. F. M., Sc.D. (New York Univ.) Coll. of the City of New York, New York, N. Y. *520 W. 114th St.*
PEGRAM, Prof. ANNIE M., A.M. (Duke) Greensboro Coll., Greensboro, N. C.
PEHRSON, Asso. Prof. E. W., A.M. (California) Univ. of Utah, Salt Lake City, Utah.
PELLETIER, Prof. ARTHUR. Higher Alg., École Poly., Montreal, Can. *8456 Drolet St.*
PENCE, SALLIE, E., A.M. (Kentucky) Instr., Univ. of Kentucky, Lexington, Ky. *635 Maxwelton Ct.*
PENN, S. S. 860 E. 161st. St., New York, N. Y.
PENNELL, W. O., B.S. (Mass. Inst. of Tech.) Chief Engr., So. Western Bell Tel. Co., St. Louis, Mo. *330 Oakwood Ave., Webster Groves, Mo.*
PERKINS, F. W., Ph.D. (Harvard) Instr., Dartmouth Coll., Hanover, N. H. *201 Hallgarten Hall.*
PERKINS, H. A., A.B. (Colby) Hampton Inst., Hampton, Va.
PERKINS, Prof. L. R., A.M. (Tufts) Middlebury Coll., Middlebury, Vt. *6 Franklin St.*
PERRY, Asst. Prof. RUTH C., A.B. (Wellesley) Dean of Women, Univ. of Chattanooga, Chattanooga, Tenn.
PETERS, J. W., Ph.D. (Johns Hopkins) Instr., Univ. of Illinois, Urbana, Ill. *360 Math. Bldg.*
PETERSON, J. K., A.M. (Harvard) 1915 Blakemore Ave., Nashville, Tenn.
PETERSON, Prof. O. J., Ph.D. (Michigan) State Teachers Coll., Emporia, Kans. *1402 Highland Pl. St.*

PETERSON, T. S., Ph.D. (Ohio State) Instr., Univ. of Michigan, Ann Arbor, Mich. *1513 S. University Ave.*
PETTERSEN, C. A., Ph.B. (Northwestern) Asst. Prin., Schurz High School, Chicago, Ill. *3922 Lowell Ave.*
PETTIT, Prof. H. P., Ph.D. (Illinois) Marquette Univ., Milwaukee, Wis. *1661 Bartlett Ave.*
PHALEN, Dean H. R., Ph.D. (Chicago) St. Stephen's Coll., Annandale-on-Hudson, N. Y.
PHILIPS, Prof. A. W., A.M. (Chicago) State Teachers Coll., Emporia, Kans.
PIAGGIO, Prof. H. T. H., D.Sc. (London) University Coll., Nottingham, England.
PICKETT, JONATHAN. Realitos, Tex.
PIERCE, Prof. JESSE, Ph.D. (Michigan) Heidelberg Univ., Tiffin, Ohio. *138 Greenfield St.*
PIERCE, Prof. T. A., Ph.D. (California) Univ. of Nebraska, Lincoln, Nebr. *1811 Pepper Ave.*
PIERPONT, Prof. JAMES, Ph.D. (Vienna) Yale Univ., New Haven, Conn. *102 Avon St.*
PIERSON, A. D., A.M. (Missouri) Jr. Coll., Kansas City, Mo. *7217 Summit St.*
PINCHERLE, Prof. SALVATORE, Sc.D. (Bologna) Univ. of Bologna, Bologna, Italy. *Viale Panzacchi 3.*
PINE, WINNIFRED F., A.B. (Brown) Teacher, St. Margaret's School, Waterbury, Conn.
PINKERTON, R. M., B.S. (Bradley Poly. Inst.) Grad. Fellow, Univ. of Virginia. *1110 Westland Ave., Charlottesville, Va.*
PIRENIAN, Asst. Prof. Z. M., M.S. (Florida) Univ. of Florida, Gainesville, Fla. *Dept. of Math.*
PLANT, Prof. L. C., M.S. (Chicago) Michigan State Coll., East Lansing, Mich.
PLIMPTON, G. A., LL.D. (Rochester), L.H.D. (New York Univ.) Sr. member, Ginn & Co., New York, N. Y. *70 Fifth Ave.*
PLOENGES, Prof. E. W., A.M. (Michigan) Kansas Wesleyan Univ., Salina, Kans.
PLYMALE, Prof. R. B., A.M. (Mercer; Columbia) Bessie Tift Coll., Forsyth, Ga.
POBANZ, J. F., Ph.D. (California) Jr. Coll., Modesto, Calif. *309 Hackberry Ave.*
POLAN, L. R., A.B. (Milton Coll.) Instr., Alfred Univ., Alfred, N. Y.
POLLARD, Asst. Prof. H. S., M.S. (Iowa) Miami Univ., Oxford Ohio.
POLLOCK, Asst. Prof. SAUL, Ph.D. (California) State Teachers Coll., Terre Haute, Ind. *2520 Deming St.*
POOL, H. A., A.M. (Minnesota). Address unknown.
POOLER, L. G., Ph.D. (Columbia) Physics, Hunter Coll., New York, N.Y. *456 Riverside Dr.*
PORITSKY, HILLEL, Ph.D. (Cornell) Teacher and Mathematician, Genl. Elec. Co., Schenectady, N. Y.
PORTER, Asso. Prof. C. S., A.M. (Clark) Amherst Coll., Amherst, Mass. *Box 735.*
PORTER, T. I., A.B. (Missouri) State Agric. Coll., Manhattan, Kans.
POST, E. L., Ph.D. (Columbia) Teacher, High School, New York, N. Y. *625 W. 152 St.*
POUND, Prof. V. E., Ph.D. (Toronto) Univ. of Buffalo, Buffalo, N. Y. *122 Berkshire Ave.*
POUNDER, Asso. Prof. I. R., Ph.D. (Chicago) Univ. of Toronto, Toronto, Ont., Can.
POWELL, J. E., M.S. (Ohio State) Instr., Michigan State Coll., East Lansing, Mich.
POWELSON, INEZ D., A.M. (California) Teacher, High School, Berkeley, Calif. *2548 Benvenue Ave.*
PRASAD, Prof. GANESH, D.Sc. (Allahabad), M.A. (Cambridge) Calcutta Univ., Calcutta, India. *2 Samavaya Mansions, Corporation St.*
PRETZ, PIUS S., A.M. (St. John's Univ.) St. Benedict's Coll., Atchison, Kans.
PRICE, G. B., A.M. (Harvard) Grad. Student and Instr., Harvard Univ., Cambridge, Mass. *J-43, John Winthrop House.*
PRIDE, Asst. Prof. H. H., Ph.D. (New York Univ.) New York Univ., New York, N. Y.
PRIESTER, Prof. G. C., Ph.D. (Michigan) Mech., Univ. of Minnesota, Minneapolis, Minn. *Coll. of Eng. and Archit.*
PRUSLIN, JOHANNA L., B.S. (New York Univ.) Instr., Hunter Coll., New York, N. Y. *132–70 Sanford Ave., Flushing, L. I., N. Y.*
PUGH, G. T., Ph.D. (Vanderbilt) Head of Dept., Winthrop Coll., Rock Hill, S. C.
PUGSLEY, Asso. Prof. D. W., M.S. (Michigan) Berea Coll., Berea, Ky. *Box 91, College P. O.*
PURCELL, E. J., A.M. (Colorado) Grad. Student, Cornell Univ., Ithaca, N. Y. *104 Overlook Rd.*
PURDIE, Asst. Prof. K. S., B.S. (Va. Milit. Inst.) Virginia Milit. Inst., Lexington, Va.
PUTNAM, Asso. Prof. R. G., Ph.D. (Chicago) New York Univ., New York, N. Y. *115 Riverview Ave., Tarrytown, N. Y.*
PUTNAM, Prof. T. M., Ph.D. (Chicago) Prof. of Math. and Dean of Undergrads., Univ. of California, Berkeley, Calif.
PYKE, A. J., B.A. (Toronto) 1228 East 56th St., Chicago, Ill.

QUARLES, LOUIS, A.B. (Michigan) Lawyer, Milwaukee, Wis. *Box 489, Route 6, Sta. C.*
QUERFELD, D. W., A.B. (James Millikin) Research Assoc., U. S. Bureau of Standards, Washington, D. C. *1301-15th St. N.W.*

QUIGLEY, Prof. MARY J., A.B. (Radcliffe) Teachers Coll. of the City of Boston. *332 Savin Hill Ave., Dorchester, Mass.*
QUILTY, PATRICK, C.E. (Cooper Union) Instr., Cooper Union, New York, N. Y. *601 W. 163 St.*
QUINN, J. J., Ph.D. (Villanova) St. Mary's Coll., St. Mary's, Kans.

RABE, L. L., A.M. (Illinois) Instr., LaSalle-Peru-Oglesby Jr. Coll., LaSalle, Ill. *1047 Joliet St.*
RADO, Prof. TIBOR, Ph.D. (Szeged) Ohio State Univ., Columbus, Ohio. *407 King Ave.*
RAGSDALE, Prof. VIRGINIA, Ph.D. (Bryn Mawr) North Carolina Coll. for Women, Greensboro, N. C.
RAIFORD, T. E., A.M. (Michigan) Instr., Univ. of Michigan, Ann Arbor, Mich. *1618 Shadford Rd.*
RAINICH, Asso. Prof. G. Y., Master in Pure Math. (Kazan) Univ. of Michigan, Ann Arbor, Mich. *602 Oswego St.*
RAINVILLE, E. D., A.B. (Colorado) Instr., Eng. Math., Univ. of Colorado, Boulder, Colo. *P. O. Box 173.*
RAMAGE, C. J., Ph.D. (Grove City) Lawyer, Saluda, S. C.
RAMBO, Asso. Prof. SUSAN M., Ph.D. (Michigan) Smith Coll., Northampton, Mass. *12 Barrett Pl.*
RAMLER, Prof. O. J., Ph.D. (Catholic Univ.) Catholic Univ., Washington, D. C. *12 Girard St. N.E.*
RAMOS, DORA, A.M. (Columbia) Prin., High School, San German, P. R.
RAMSDELL, Prof. G. E., A.M. (Harvard) Bates Coll., Lewiston, Me. *40 Mountain Ave.*
RAMSEY, Asso. Prof. MARGARET, A.M. (Oregon) Albany Coll., Albany, Ore.
RANDALL, Prof. A. W., A.M. (Colorado) State Indus. Coll., Prairie View, Tex. *Box 63.*
RANDOLPH, J. F., A.M. (Michigan) Cornell Univ., Ithaca, N. Y. *White Hall.*
RANKIN, A. W. Elec. Lab., Elec. Service Supplies Co., Philadelphia, Pa. *4526 N. Mole St.*
RANKIN, Prof. J. M. Coll. of Idaho, Caldwell, Idaho. *1810 Ash St.*
RANKIN, Prof. W. W., Jr., A.M. (North Carolina) Duke Univ., Durham, N. C.
RANSOM, Prof. W. R., A.M. (Tufts; Harvard) Tufts Coll., Tufts College, Mass. *29 Sawyer Ave.*
RANUM, Prof. ARTHUR, Ph.D. (Chicago) Cornell Univ. Ithaca, N. Y. *3 Central Ave.*
RASCHE, Prof. W. H. Mechanism, Virginia Poly. Inst., Blacksburg, Va.
RASEL, D. M., M.S. (Washington and Jefferson) Instr., Physics, Washington and Jefferson Coll., Washington, Pa.
RASMUSEN, RUTH B., M.S. (Chicago) Instr., South Dakota State Coll., Brookings, S. D.
RASOR, Prof. S. E., M.S. (Chicago) Ohio State Univ., Columbus, Ohio. *1594 Neil Ave.*
RAU, Prof. A. G., Ph.D. (Lehigh) Moravian Coll., Bethlehem, Pa. *38 W. Market St.*
RAUDENBUSH, H. W., Jr., A.M. (Columbia) Instr., Columbia Univ., New York, N. Y. *Hamilton Hall.*
RAWLINS, Asso. Prof. C. H., Jr., Ph.D. (Johns Hopkins) Postgrad. School, U. S. Naval Acad., Annapolis, Md. *13 Franklin St.*
RAYNOR, Asst. Prof. G. E., Ph.D. (Princeton) Lehigh Univ., Bethlehem, Pa. *704 Fifth Ave.*
REA, Asst. Prof. P. L., A.M. (Illinois) Marietta Coll., Marietta, Ohio. *On leave 1931–32, Ohio State Univ., Columbus, Ohio.*
REAGAN, Prof. C. A., A.M. (Kansas) Friends Univ., Wichita, Kans.
REAVES, Prof. CAROLINE M., A.M. (Oklahoma) Coker Coll., Hartsville, S. C.
REAVES, Prof. S. W., Ph.D. (Chicago) Dean of Coll. of Arts and Sc., Univ. of Oklahoma, Norman, Okla. *527 Chautauqua Ave.*
REBARKER, Prof. HERBERT, Ph.D. (Peabody) East Carolina Teachers Coll., Greenville, N. C.
RECHARD, Prof. O. H., Ph.D. (Wisconsin) Univ. of Wyoming, Laramie, Wyo. *601 S. 13th St.*
RECHT, A. W., A.M. (Denver) Instr., Math. and Astr., Univ. of Denver, Denver, Colo. *935 E. Ellsworth Ave.*
REDDEN, Asso. Prof. J. E., M.S. (Iowa State Coll.) John Tarleton Agric. Coll., Stephenville, Tex. *Box 568.*
REDDICK, Prof. H. W., Ph.D. (Columbia) Cooper Union, New York, N. Y.
REDDITT, B. H., A.M. (Johns Hopkins) Columbia, La.
REECE, Prof. R. H., A.M. (Colorado) New Mexico School of Mines, Socorro, N. Mex.
REED, Asso. Prof. F. W., Ph.D. (Virginia) Ohio Univ., Athens, Ohio.
REED, L. J., Ph.D. (Pennsylvania) School of Hygiene, Baltimore, Md. *615 N. Wolfe St.*
REEN, Asst. Prof. C. G., M.S.E. (Michigan) Civil Eng., Gettysburg Coll., Gettysburg, Pa. *25 Chambersburg St.*
REES, Asso. Prof. C. J., A.M. (Chicago) Univ. of Delaware, Newark, Del.
REES, Asso. Prof. E. L., C.E. (Kentucky), A.M. (Chicago) Univ. of Kentucky, Lexington, Ky. *200 University Ave.*

REES, MINA S., Ph.D. (Chicago) Instr., Hunter Coll., New York, N. Y. *2292 Loring Pl.*
REES, P. K., A.M. (Texas) Grad. Student, Rice Inst., Houston, Tex. *1719 Brun St.*
REES, W. A., A.M. (Texas) Instr., Jr. Coll., Houston, Tex. *1719 Brun St.*
REEVE, Prof. W. D., Ph.D. (Minnesota) Teachers Coll., Columbia Univ., New York, N. Y.
REID, Prof. L. W., Ph.D. (Göttingen) Haverford Coll., Haverford, Pa.
REID, W. T., Ph.D. (Texas) Instr., Univ. of Chicago, Chicago, Ill. *Box 37, Eckhart Hall.*
REILLY, Prof. J. F., Ph.D. (Iowa) Univ. of Iowa, Iowa City, Iowa. *Room 212, Physics Bldg.*
REINSCH, Prof. B. P., Ph.D. (Illinois) School of Eng., Southern Methodist Univ., Dallas, Tex.
REISING, J. A. Teacher, Central High School and Indiana Univ. Extension, Ft. Wayne, Ind. *2527 S. Harrison St.*
REMICK, Prof. B. L., Ph.M. (Cornell Coll.) State Agric. Coll., Manhattan, Kans.
RENNER, THERESA M., M.S. (Illinois) Registrar, Blackburn Coll., Carlinville, Ill. *324 N. Oak St.*
REYNOLDS, Prof. C. N., Ph.D. (Harvard) West Virginia Univ., Morgantown, W. Va.
REYNOLDS, Prof. J. B., Ph.D. (Moravian) Mech., Lehigh Univ., Bethlehem, Pa. *732 W. Broad St.*
REYNOLDS, LENA E., A.M. (California) Head of Dept., Jr. Coll., Fullerton, Calif.
REYNOLDS, W. F., A.B. (Johns Hopkins) Sr. Mathematician, U. S. Coast and Geodetic Survey, Washington, D. C. *848 W. 37th St., Baltimore, Md.*
RHODES, C. E., A.B. (Cornell) Instr., Univ. of Cincinnati, Cincinnati, Ohio.
RHODES, Prof. M. C., Ph.D. (Peabody) Head of Dept., Univ. of Mississippi, University, Miss. *Box 422.*
RICE, Prof. HARRIS, A.M. (Harvard) Worcester Poly. Inst., Worcester, Mass.
RICE, J. M., E.E. (Lehigh) Exec. Engr., Curtiss Aeroplane and Motor Co., Buffalo, N. Y. *279 Colvin Ave.*
RICE, Asso. Prof. J. N., Ph.D. (Catholic Univ.) Catholic Univ., Washington, D. C. *3326 Thirteenth St. N.E.*
RICE, Asst. Prof. L. H., A.B. (Syracuse) Mass. Inst. of Tech., Cambridge, Mass.
RICHARDS, W. A., A.M. (Chicago) Teacher, Morton Jr. Coll., Cicero, Ill. *3305 Ridgeland Ave., Berwyn, Ill.*
RICHARDSON, Prof. A. V., M.A. (Cambridge) Bishops Coll., Lennoxville, Quebec, P. Q., Can.
RICHARDSON, Prof. C. H., Ph.D. (Michigan) Bucknell Univ., Lewisburg, Pa.
RICHARDSON, Dean R. G. D., Ph.D. (Yale) Grad. School, Brown Univ., Providence, R. I.
RICHERT, Prof. D. H., A.M. (Colorado) Bethel Coll., Newton, Kans.
RICHESON, Asst. Prof. A. W., Ph. D. (Johns Hopkins) Univ. of Maryland, College Park, Md. *306 E. 32nd St., Baltimore, Md.*
RICHMOND, SUSAN V., A.B. (Randolph-Macon Woman's Coll.) Teacher, Western High School, Washington, D. C. *2126 Connecticut Ave. N. W.*
RICHTMEYER, Asst. Prof. C. C., A.M. (Peabody) State Teachers Coll., Mt. Pleasant, Mich.
RICKARD, Asst. Prof. HORTENSE, A.M. (Ohio State) Ohio State Univ., Columbus, Ohio. *79 Beechwold Rd.*
RIDER, Asso. Prof. P. R., Ph.D. (Yale) Washington Univ., St. Louis, Mo.
RIES, H. F., A.B. (Michigan) Asst. Actuary, Guaranty Life Ins. Co., Davenport, Iowa. *2529 Middle Rd.*
RIESBECK, LAURA, B.S. in Educ. (Ohio Univ.) Teacher, High School, Zanesville, Ohio. *1001 Greenwood Ave.*
RIETZ, Prof. H. L., Ph.D. (Cornell) Univ. of Iowa, Iowa City, Iowa.
RIGGS, Prof. N. C., M.S. (Harvard) Mech., Carnegie Inst. of Tech., Pittsburgh, Pa.
RISLEY, W. J., A.M. (Illinois) Plaza Hotel, Denver, Colo.
RISSELMAN, Prof. W. C., Ph.D. (Minnesota) Northern Arizona Teachers Coll., Flagstaff, Ariz.
RITER, H. E., M.A. (Manitoba) Math. Master, Provincial Normal School, Winnipeg, Man., Can. *909 Strathcona St.*
RITT, Prof. J. F., Ph.D. (Columbia) Columbia Univ., New York, N. Y. *Dept. of Math.*
ROBB, D. L., A.M. (Pittsburgh) Grad. Asst., Univ. of Pittsburgh. *403 Federal St., Butler, Pa.*
ROBB, J. M., A.M. (Michigan) Teacher, Math. and Physics, Jr. Coll., Taft, Calif. *727 San Emidio St.*
ROBBINS, ALICE V., Ph.M. (Chicago) Teacher, State Teachers Coll., Mankato, Minn. *418 S. 4th St.*
ROBBINS, Asst. Prof. C. K., A.M. (Harvard) Purdue Univ., W. LaFayette, Ind. *418 Vine St.*
ROBERTS, Prof. B. D., A.M. (Indiana) Parsons Coll., Fairfield, Iowa. *409 W. Carpenter St.*
ROBERTS, H. M., B.M.E. (Minnesota) Efficiency Engr., Sears, Roebuck & Co., Minneapolis, Minn. *3225 2nd Ave S.*

ROBERTS, Asst. Prof. J. H., Ph.D. (Texas) Duke Univ., Durham, N. C. *Box 4708.*
ROBERTS, Prof. MARIA M., B.L. (Iowa State Coll.) Prof. of Math. and Dean, Iowa State Coll., Ames, Iowa.
ROBERTS, WALTER, B.S. (Pennsylvania) Head of Dept., W. Philadelphia High School, Philadelphia, Pa. *3419 N. 22nd St.*
ROBERTSON, FRED, A.M. (Indiana) Instr., Iowa State Coll., Ames, Iowa. *Dept of Math.*
ROBINSON, Asst. Prof. A. J., M.S. (Emory) Alabama Poly. Inst., Auburn, Ala.
ROBINSON, G. EDNA, A.M. (Missouri) 1507 Windsor St., Columbia, Mo.
ROBINSON, Prof. H. A., Ph.D. (Johns Hopkins) Agnes Scott Coll., Decatur, Ga. *123 College Pl.*
ROBINSON, L. V., Ph.D. (Harvard) Astronomer, Harvard Coll. Observ., Cambridge, Mass.
ROBINSON, ROBIN, Ph.D. (Harvard) Instr., Dartmouth Coll., Hanover, N. H. *21 Prospect St.*
ROBINSON, FLORA EATON (Mrs. W. F.) Registrar and Head of Dept., Mars Hill Coll., Mars Hill, N. C.
ROBISON, G. M., Ph.D. (Cornell) Faculty Club, Durham, N. C.
RODGERS, Dean T. G., A.M. (Wisconsin) New Mexico Normal Univ., Las Vegas, N. Mex. *1018 Fourth St.*
ROESER, H. M., M.S. (George Washington) Engr., Physicist, U. S. Bureau of Standards, Chicago, Ill. *5800 W. 69th St., Clearing Sta.*
ROEVER, Prof. W. H., Ph.D. (Harvard) Pure Math., Washington Univ., St. Louis, Mo.
ROGERS, Dean J. C., A.M. (Columbia) Dean and Prof. of Math., Piedmont Coll., Demorest, Ga.
ROGERS, H. P., A.M. (Illinois) Asst., Univ. of Illinois. *616 E. Daniel St., Champaign, Ill.*
ROMAN, Asst. Prof. IRWIN, Ph.D. (Chicago) Math. and Physics, Michigan Coll. of Mining and Tech., Houghton, Mich. *Hubbell Hall.*
ROOD, MARION B., M.S. (Michigan) 1014 Church St., Ann Arbor, Mich.
ROOS, C. F., Ph.D. (Rice) Permanent Secy., Amer. Assn. for the Adv. of Sc., Washington, D. C. *Smithsonian Inst. Bldg.*
ROOT, Prof. R. E., Ph.D. (Chicago) U. S. Naval Acad., Annapolis, Md. *7 Franklin St.*
ROOTS, Prof. Y. K., M.S. (New York Univ.) Math. and Physics, Findlay Coll., Findlay, Ohio.
ROSEBRUGH, Prof. T. R., M.A. (Toronto) Elec. Eng., Univ. of Toronto, Toronto, Ont., Can. *92 Walmer Rd.*
ROSENBACH, Asso. Prof. J. B., M.S. (Illinois) Carnegie Inst. of Tech., Pittsburgh, Pa. *2526 Beechwood Blvd.*
ROSENBAUM, JOSEPH, Ph.D. (Cornell) Instr., The Milford School, Milford, Conn.
ROSENGARTEN, Prof. GEORGE, Ph.D. (Pennsylvania) W. Phila. High School for Boys, Philadelphia, Pa. *1105 Edgewood Rd., Upper Darby, Pa.*
ROSSKOPF, M. F., A.M. (Minnesota) Instr., Brown Univ., Providence, R. I. *63 Charles Field St.*
ROTE, L. J. Practicing Attorney, Denver, Colo. *260 S. Broadway.*
ROTH, Asst. Prof. W. E., Ph.D. (Wisconsin) Univ. of Wisconsin, Extension Div., Milwaukee, Wis. *2103 Wisconsin Ave.*
ROTHERMEL, FLORENCE. Teacher, W. Phila. High School, Philadelphia, Pa. *320 S. 42nd St.*
ROTHROCK, Dean D. A., Ph.D. (Leipzig) Indiana Univ., Bloomington, Ind. *1000 Atwater Ave.*
ROULTON, J. A. Research Engr., Atlantic Refining Co., Philadelphia, Pa. *LeRoy Court Apts., 60th St. and Warrington Ave.*
ROUSE, Asst. Prof. L. J., Ph.D. (Michigan) Univ. of Michigan, Ann Arbor, Mich.
ROWE, Prof. C. H., M.A. (Dublin) Univ. of Dublin, Dublin, Ireland. *38 Trinity College.*
ROWE, Pres. J. E., Ph.D. (Johns Hopkins) Clarkson Coll. of Tech., Potsdam, N. Y.
ROWLAND, Prof. S. A. Ohio Wesleyan Univ., Delaware, Ohio. *49 Oak Hill Ave.*
RUDERMAN, H. D. Student, Coll. of the City of New York. *718 Ave. P, Brooklyn, N. Y.*
RUMNEY, ETHEL A., M.S. (Chicago) 309 N. Main St., Sandwich, Ill.
RUMSEY, MARY B., A.M. (Illinois) Asst., Univ. of Illinois, Urbana, Ill. *Univ. Sta.*
RUNDSTROM, Prof. INEZ, Fil. Kand. (Uppsala, Sweden) Gustavus Adolphus Coll., St. Peter, Minn.
RUNGE, Asst. Prof. LULU L., A.M. (Wisconsin) Univ. of Nebraska, Lincoln, Nebr.
RUNNING, Prof. T. R., Ph.D. (Wisconsin) Univ. of Michigan, Ann Arbor, Mich. *1019 Michigan Ave.*
RUPP, Asso. Prof. C. A., Ph.D. (Chicago) Pennsylvania State Coll., State College, Pa.
RUSK, Prof. W. J., M.A. (Toronto) Math. and Astr., Grinnell Coll., Grinnell, Iowa. *1415 Park St.*
RUSSELL, BEULAH, A.M. (Chicago) Williamsburg, Va.

RUSSELL, Prof. W. P., A.M. (Cumberland) Pomona Coll., Claremont, Calif.
RUTLEDGE, Asso. Prof. GEORGE, Ph.D. (Illinois) Mass. Inst. of Tech., Cambridge, Mass. *29 Bellevue Rd., Belmont, Mass.*
RYAN, MARGARET M., A.M. (Syracuse) Grad. Asst., Syracuse Univ., Syracuse, N. Y. *415 Bryant Ave.*

SABIN, MARY S., A.M. (Denver) 730 Emerson St., Denver, Colo.
SAFFORD, Prof. F. H., Ph.D. (Harvard) Univ. of Pennsylvania, Philadelphia, Pa. *College Hall.*
SAGEN, G. O., A.M. (California) Instr., Kern Co. Jr. Coll., Bakersfield, Calif.
SAIBEL, Asst. Prof. E. A., Ph.D. (Mass. Inst. of Tech.) Carnegie Inst. of Tech., Pittsburgh, Pa.
SALAS-EDWARDS, Prof. RAMON. Dynamics, Univ. of Chile, Santiago, Chile. *Delicias 1876.*
SALKOVER, Asst. Prof. MEYER, Ph.D. (Yale) Univ. of Cincinnati, Cincinnati, Ohio. *3467 Ruther St.*
SALVOSA, Prof. L. R., Ph.D. (Michigan) Forest Eng., Univ. of the Philippines, Manila, P. I.
SANCHEZ-DIAZ, Asst. Prof. RAFAEL, B.S. (Porto Rico) Coll. of A. and M., Univ. of Porto Rico, Mayaguez, P. R. *P. O. Box 231.*
SANDERS, Prof. S. T., M.S. (Chicago) La. State Univ., Baton Rouge, La. *714 Mills Ave.*
SANFORD, Asst. Prof. VERA, Ph.D. (Columbia) School of Education, Western Reserve Univ. Cleveland Ohio.
SAUNDERS, FAITH, A.M. (Missouri) Maysville, DeKalb Co., Mo.
SAUREL, Prof. PAUL, Sc.D. (Bordeaux, France) Coll. of the City of New York, New York, N. Y.
SAUTÉ, Asst. Prof. GEORGE, A.M. (Brown) Cleveland Coll., Cleveland, Ohio. *3528 Ingleside Rd., Shaker Hts.*
SAVARY, C. M., C.E. Chief of Geodesy and Cartography, Dept. of Lands and Forests, Quebec, P. Q., Can. *586 St. Foye Rd.*
SCAMMON, Prof. R. E., Ph.D. (Harvard) Anatomy, Univ. of Minnesota, Minneapolis, Minn. *Inst. of Anatomy, Univ. of Minn.*
SCARBOROUGH, Asst. Prof. J. B., Ph.D. (Johns Hopkins) U. S. Naval Acad., Annapolis, Md. *P. O. Box 332.*
SCARBOROUGH, Prof. J. H., Ph.D. (Vanderbilt) State Teachers Coll., Warrensburg, Mo.
SCHAEFFER, NEDA F. (Mrs. W. E.), A.M. (Boston) 331 E. Main St., Kent, Ohio.
SCHEIER, Prof. MAURICE, A.M. (St. Bonaventure's) Holy Name Coll., Catholic Univ., Washington, D. C. *18th and Sheppard Sts. N.E.*
SCHELKUNOFF, S. A., Ph.D. (Columbia) Bell Telephone Labs. New York, N. Y. *463 West St.*
SCHEY, OLE, B.S. (Minnesota) Asst. in Educ. Psych., Univ. of Minnesota, Minneapolis, Minn. *502-15th Ave. S.E.*
SCHLAUCH, HELEN M., A.M. (Cornell) Instr., Hunter Coll., New York, N. Y. *219 Division Ave., Hasbrouck Hts., N. J.*
SCHLAUCH, Asst. Prof. W. S., A.M. (Columbia) Acctg., School of Commerce, New York Univ., New York, N. Y. *219 Division Ave., Hasbrouck Hts., N. J.*
SCHMEISER, MABEL F., Ph.D. (Ohio State) Head of Dept., State Teachers Coll., Wayne, Nebr. *315 E. Tenth St.*
SCHNELL, L. J., B.S. in E.E. (Colorado) Instr. and Acting Head of Dept., Augsburg Coll., Minneapolis, Minn. *8th St. and 21st Ave. S.*
SCHOONMAKER, Prof. HAZEL E., Ph.D. (Cornell) Hartwick Coll., Oneonta, N. Y.
SCHOONOVER, Asst. Prof. R. H., A.M. (Michigan) Coll. of the City of Detroit, Detroit, Mich. *4841 Cass Ave.*
SCHORLING, Asso. Prof. RALEIGH, Ph.D. (Michigan) School of Educ., Univ. of Michigan, Ann Arbor, Mich.
SCHOUTEN, Prof. Dr. J. A. Tech. Univ., Delft, Holland. *Rotterdamsche Weg 111.*
SCHREIBER, Asso. Prof. E. W., A.M. (Chicago) State Teachers Coll., Macomb, Ill. *456 S. Edwards St.*
SCHROEDER, Asso. Prof. C. E., A.M. (Boston Coll.) Boston Coll., Boston, Mass.
SCHUB, PINCUS, Ph.D. (Dropsie) Teacher, Gratz Coll., New York, N. Y. *207 E. Broadway.*
SCHULTZ, N. L. Student Asst., Univ. of Maine, Orono, Me. *40 Middle St.*
SCHUYLER, ELMER, M.S. (Lafayette) Instr., Bay Ridge High School, Brooklyn, N. Y. *87 71st St.*
SCHWEITZER, A. R., Ph.D. (Chicago) 452 Oakdale Ave., Chicago, Ill.
SCOTT, Prof. T. P., A.M. (Mississippi) State Teachers Coll., Memphis, Tenn.
SEARCY, Asst. Prof. C. L., C.E. (Purdue), A.M. (California) Univ. of Nevada, Reno, Nev.
SEELY, CAROLINE E., Ph.D. (Columbia) 501 W. 116th St., New York, N. Y.
SEIDEL, WLADIMIR, Ph.D. (Munich) National Research Fellow, Harvard Univ., Cambridge, Mass. *30 Mount Auburn St.*

SEIDLIN, Prof. JOSEPH, Ph.D. (Columbia) Alfred Univ., Alfred, N. Y.
SEIVERLING, I. F., A.M. (Columbia) Head of Dept., State Teachers Coll., Millersville, Pa.
SELHEIMER, C. W., Jr., M.S. (Michigan) Chem. Engr., Chemical Div., Proctor and Gamble Co., Ivorydale, Ohio.
SELL, WILLIAM, A.M. (Alabama) Instr., Univ. of Alabama, University, Ala. *Box 931.*
SELLEW, Prof. G. T., Ph.D. (Yale) Knox Coll., Galesburg, Ill.
SENSENIG, WAYNE, Ph.D. (Pennsylvania) 309 Bangor Rd., Bala-Cynwyd, Mont. Co., Pa.
SEWELL, J. S., Grad. (U. S. Milit. Acad.) Pres., Alabama Marble Co., Birmingham, Ala. *2801 Mountain Ave.*
SHANNON, Prof. J. I., A.M. (St. Louis) Dean, School of Philos. and Sc., St. Louis Univ., St. Louis, Mo. *215 N. Grand Ave.*
SHAUB, Asst. Prof. H. C., A.M. (Dartmouth) Washington and Jefferson Coll., Washington, Pa. *440 E. Bean St.*
SHAW, Asst. Prof. A. A., Ph.D. (California) Univ. of Arizona, Tucson, Ariz.
SHAW, R. S., A.M. (Columbia) Physics, Coll. of the City of New York, New York, N. Y.
SHEFFER, Asst. Prof. I. M., Ph.D. (Harvard) Pennsylvania State Coll., State College, Pa. *12 Liberal Arts Bldg.*
SHELDON, Prof. E. W., Ph.D. (Yale) Univ. of Alberta, Edmonton South, Alta., Can.
SHELLENBARGER, R. C., A.M. (Michigan) Head of Dept., Jr. Coll., Bay City, Mich. *248 N. Grant St.*
SHENTON, Prof. W. F., Ph.D. (Johns Hopkins) American Univ., Washington, D. C. *3605 Porter St. N.W.*
SHERER, C. R., A.M. (Nebraska) Head of Dept., Texas Christian Univ., Fort Worth, Tex.
SHERMAN, C. C., M.S. (Iowa) 505 K Ave. East, Oskaloosa, Iowa.
SHERWOOD, Prof. G. E. F., Ph.D. (Chicago) Univ. of California at Los Angeles, Los Angeles, Calif. *926 Hyperion Ave.*
SHEWHART, W. A., Ph.D. (California) Engineer, Bell Telephone Labs., New York, N. Y. *158 Lake Drive, Mountain Lakes, N. J.*
SHIBLI, Asst. Prof. JABIR, A.M. (Wisconsin) Pennsylvania State Coll., State College, Pa. *Dept. of Math.*
SHIRK, Prof. J. A. G., M.S. (Kansas) State Teachers Coll., Pittsburg, Kans. *116 E. Lindberg Ave.*
SHIRLEY, PAULINE, A.B. (Baylor) Teacher, Jr. Coll., Wichita Falls, Tex. *2141 Ave. G.*
SHIVELY, Prof. L. S., Ph.D. (Chicago) Ball Teachers Coll., Muncie, Ind. *407 Riverside Ave.*
SHOHAT, Asst. Prof. J. A., Magister of Pure Math. (Petrograd) Univ. of Pennsylvania, Philadelphia, Pa. *R 308, Bennett Hall.*
SHOOK, Asst. Prof. C. A., Ph.D. (Johns Hopkins) Lehigh Univ., Bethlehem, Pa. *1624 Millard St.*
SHORR, ROSE, A.B. (Hunter) Teacher, Manual Training High School, Brooklyn, N. Y. *29 Schenck Ave.*
SHORT, Pres. C. A., M.S. (Delaware) Wesley Collegiate Inst., Dover, Del.
SHORT, Asst. Prof. JESSIE M., A.M. (Carleton) Reed Coll., Portland, Ore.
SHORT, Prof. W. T., A.B. (Okla. Baptist Coll.,) Head of Dept., Oklahoma Baptist Coll., Shawnee, Okla.
SHOVER, C. GRACE, A.M. (Ohio State) Instr., Connecticut Coll., New London, Conn.
SHOWMAN, H. M., A.M. (Harvard) Lecturer and Univ. Recorder, Univ. of California at Los Angeles, Los Angeles, Calif. *912 Hyperion Ave.*
SHRINER, W. O., Ph.D. (Michigan) Head of Dept., State Teachers Coll., Terre Haute, Ind.
SHUMAN, J. W., B.S. (Mass. Inst. of Tech.) Secy-Treas., Power Eng. Co.; Consulting Engr.; Minneapolis, Minn. *716 Metro. Life Bldg.*
SHUMWAY, Asso. Prof. R. R., A.B. (Minnesota) Univ. of Minnesota, Minneapolis, Minn.
SHUSTER, Asst. Prof. C. N., A.M. (Columbia) Head of Dept., State Teachers Coll., Trenton, N. J. *2393 Pennington Rd.*
SICELOFF, Asso. Prof. L. P., Ph.D. (Columbia) Columbia Univ., New York, N. Y.
SILVERMAN, Prof. L. L., Ph.D. (Missouri) Dartmouth Coll., Hanover, N. H.
SIMESTER, Asst. Prof. J. H., M.A. (Toronto) Univ. of Louisville, Louisville, Ky.
SIMMONS, Asso. Prof. H. A., Ph.D. (Chicago) Northwestern Univ., Evanston, Ill. *2125½ Ridge Ave.*
SIMON, Prof. W. G., Ph.D. (Chicago) Adelbert Coll., Western Reserve Univ., Cleveland, Ohio.
SIMONS, Prof. LAO G., Ph.D. (Columbia) Hunter College, New York, N. Y. *180 W. 88th St.*
SIMPSON, Prof. T. M., Ph.D. (Wisconsin) Univ. of Florida, Gainesville, Fla. *547 S. 9th St.*
SIMPSON, Prof. T. McN., Jr., Ph.D. (Chicago) Randolph-Macon Coll., Ashland, Va.
SINCLAIR, Prof. MARY EMILY, Ph.D. (Chicago) Oberlin Coll., Oberlin, Ohio. *260 Oak St.*
SINGER, Prof. S. A., A.M. (Capital) Capital Univ., Columbus, Ohio. *2322 E. Main St.*

SINKOV, ABRAHAM, A.M. (Columbia) Jr. Mathematician, U. S. Civil Serv., Washington, D. C. *1412 Chapin St. N.W.*
SIROKY, Asso. Prof. EDMOND, M.S. (Washington Univ.) Washington Univ., St. Louis, Mo.
SISAM, Prof. C. H., Ph.D. (Cornell) Colorado Coll., Colorado Springs, Colo. *816 N. Weber St.*
SKARSTEDT, Prof. MARCUS, Ph.D. (California) Whittier Coll., Whittier, Calif.
SKELDING, A. Z., A.B. (C.C.N.Y) Asst. Actuary, Natl. Council on Compensation Ins., New York, N. Y. *116 Stanton Ave., Baldwin, N. Y.*
SKILES, Dean W. V., A.M. (Harvard) Georgia School of Tech., Atlanta, Ga.
SKINNER, Prof. E. B., Ph.D. (Chicago) Univ. of Wisconsin, Madison, Wis. *210 Lathrop St.*
SLAUGHT, Prof. H. E., Ph.D. (Chicago) Univ. of Chicago, Chicago, Ill.
SLEIGHT, Prof. E. R., A.M. (Albion) Albion Coll., Albion, Mich.
SLOBIN, Prof. H. L., Ph.D. (Clark) Univ. of New Hampshire, Durham, N. H.
SMAIL, Prof. L. L., Ph.D. (Columbia) Lehigh Univ., Bethlehem, Pa.
SMILEY, Asst. Prof. C. H., Ph.D. (California) Brown Univ., Providence, R. I.
SMINK, R. D., M.S. (Bucknell) Teacher, Sr. High School, Williamsport, Pa. *667 Sixth Ave.*
SMITH, A. W., Ph.D. (Chicago) Colgate Univ., Hamilton, N. Y.
SMITH, Prof. C. D., Ph.D. (Iowa) Mississippi A. and M. Coll., A. and M. College, Miss.
SMITH, Prof. CLARA E., Ph.D. (Yale) Wellesley Coll., Wellesley, Mass. *14 Waban St.*
SMITH, Mrs. CONSTANCE FITCH, A.M. (Arizona) Pima Co. School Supt., Tucson, Ariz. *Box 457, R.F.D. 2.*
SMITH, C. W., A.B. (Minnesota) State Teachers Coll., Superior, Wis.
SMITH, Prof. DAVID EUGENE, Ph.D., LL.D. (Syracuse) Emeritus, Columbia Univ., New York, N. Y. *501 W. 120th St.*
SMITH, Prof. D. M., Ph.D. (Chicago) Georgia School of Tech., Atlanta, Ga.
SMITH, Prof. EDWIN R., Ph.D. (Munich) Head of Dept., Iowa State Coll., Ames, Iowa.
SMITH, Prof. ELMER R., A.M. (Vanderbilt) Secy. to the Faculty, State Coll. for Women, Tallahassee, Fla. *79 College Ave.*
SMITH, Prof. E. S., Ph.D. (Virginia) Univ. of Cincinnati, Cincinnati, Ohio.
SMITH, F. E., Ph.D. (Catholic Univ.) Instr., Brooklyn Coll., Brooklyn, N. Y. *Box 212. Wortendyke, N. J.*
SMITH, Asso. Prof. G. W., Ph.D. (Illinois) Univ. of Kansas, Lawrence, Kans. *1730 Illinois.*
SMITH, Asso. Prof. H. L., Ph.D. (Chicago) Louisiana State Univ., Baton Rouge, La.
SMITH, Asst. Prof. H. W., M.S. (Chicago) Oklahoma A. and M. Coll., Stillwater, Okla.
SMITH, Prof. I. W., A.M. (Illinois) North Dakota Agric. Coll., Fargo, N. D. *1126 13th St. N.*
SMITH, Rev. J. P., A.M. (Woodstock) St. Peters Coll., Jersey City, N. J. *144 Grand St.*
SMITH, Prof. L. W., Ph.D. (Washington and Lee) Washington and Lee Univ., Lexington, Va.
SMITH, Pres. M. G., Ph.D. (Illinois) Spring Arbor Sem. and Jr. Coll., Spring Arbor, Mich.
SMITH, Prof. MARTHA L., M.S. (Chicago) Virginia Union Univ., Richmond, Va.
SMITH, Prof. P. F., Ph.D. (Yale) Yale Univ., Sheffield Sc. Sch., New Haven, Conn. *330 Willow St.*
SMITH, Asst. Prof. R. F., M.S. (New York Univ.) Coll. of the City of New York, New York, N. Y. *463 W. 144th St.*
SMITH, R. R., A.B. (Yale) 12 E. 41st St., New York, N. Y.
SMITH, S. J., A.M. (Pittsburgh) Instr., State Teachers Coll., Lock Haven, Pa.
SMITH, Asst. Prof. W. F., A.M. (Kentucky) New River State Coll., Montgomery, W. Va. *615 First Ave.*
SMITH, Prof. W. M., Ph.D. (Columbia) Lafayette Coll., Easton, Pa.
SMYTH, Sister M. PAULINE, A.M. (Canisius) Aquinas Inst., Rochester, N. Y. *1127 Dewey Ave.*
SMYTH, RUTH B. (Mrs. B. J.), A.M. (Oberlin) Instr., part-time, Oberlin Coll., Oberlin, Ohio. *93 E. Lorain St.*
SNEDECOR, Asso. Prof. G. W., A.M. (Michigan) Physics, Iowa State Coll., Ames, Iowa. *807 Hodge Ave.*
SNYDER, Asst. Prof. A. D., A.M. (Wisconsin) Union Coll., Schenectady, N. Y. *1592 Union St.*
SNYDER, Prof. VIRGIL, Ph.D. (Göttingen) Cornell Univ., Ithaca, N. Y. *214 University Ave.*
SOKOLNIKOFF, Asst. Prof. I. S., Ph.D. (Wisconsin) Univ. of Wisconsin, Madison, Wis. *Dept. of Math.*
SOKOLNIKOFF, ELIZABETH STAFFORD (Mrs. I. S.), Ph.D. (Wisconsin) Instr., Univ. of Wisconsin, Madison, Wis.
SOLUM, Asst. Prof. A. K., A.B. (St. Olaf) St. Olaf Coll., Northfield, Minn. *307 Manitou St.*
SOUSLEY, Prof. C. P., Ph.D. (Johns Hopkins) Rose Poly. Inst., Terre Haute, Ind. *92 Potomac St.*
SPANN, Asst. Prof. J. T., B.S. (Mississippi) Univ. of Maryland, College Park, Md.

SPARKS, Prof. F. W., Ph.D. (Chicago) Texas Tech. Coll., Lubbock, Tex. *Box 94, Tech. Sta.*
SPARROW, Prof. C. M., Ph.D. (Johns Hopkins) Physics, Univ. of Virginia, University, Va.
SPEAR, Prof. JOSEPH, A.B. (Harvard) Chm. of Dept., School of Eng., Northeastern Univ., Boston, Mass. *316 Huntington Ave.*
SPEEKER, Asso. Prof. G. G., A.M. (Indiana) Michigan State Coll., East Lansing, Mich.
SPENCELEY, Asso. Prof. G. W., A.M. (Harvard) Miami Univ., Oxford, Ohio. *100 E. Walnut St.*
SPENCER, Prof. MARY C., M.S. (Cornell). Sophie Newcomb Coll., New Orleans, La.
SPENCER, VIVIAN E., A.M. (Oberlin) Grad. Asst., Univ. of Pittsburgh, Pittsburgh, Pa. *Webster Hall, Oakland Sta.*
SPENCER, W. A., B.S. (Nebraska) Instr., Armour Inst. of Tech., Chicago, Ill.
SPERRY, MAY J., A.M. (Brown) Instr., Syracuse Univ., Syracuse, N. Y. *Dept. of Math.*
SPERRY, Asso. Prof. PAULINE, Ph.D. (Chicago) Univ. of California, Berkeley, Calif. *1194 Cragmont Ave.*
SPIES, Prof. ANTOINETTE, Ph.D. (Fordham) Head of Dept., Coll. of the Sacred Heart, Manhattanville, New York, N. Y.
SPINKS, M. J. Chief Engr., Champion Bridge Co., Wilmington, Ohio. *Box 594.*
SPOONER, Prof. C. C., A.M. (Amherst) State Teachers Coll., Marquette, Mich. *210 E. Prospect St.*
SROMOVSKY, Rev. R. A., A.M. (Wisconsin) Grad. Student, Univ. of Wisconsin, Madison, Wis. *120 W. Johnson St.*
STAFFORD, ANNA A., A.B. (Western Coll.) Grad. Student, Univ. of Chicago, Chicago, Ill. *184 N. Wildwood Rd., Lake Forest, Ill.*
STAGER, H. W., Ph.D. (California) 833 Lincoln Ave., Palo Alto, Calif.
STAGNER, MARGUERITE E., B.S. (Iowa State Coll.) Teacher, High School, Glenham, S. D.
STANWICK, C. A., B.S. in E.E. (Washington) Elec. Engr., 33 Beech St., East Orange, N. J.
STARK, Asst. Prof. MARION E., Ph.D. (Chicago) Wellesley Coll., Wellesley, Mass. *Wilder Hall.*
STARRETT, A. L., A.M. (Harvard) Instr., Hobart Coll., Geneva, N. Y.
STAUFFER, J. R. K., M.S. (Chicago) Grad. Student, Univ. of Chicago, Chicago, Ill. *6020 Harper Ave.*
STEED, Asso. Prof. D. V., Ph.D. (California) Univ. of Southern California, Los Angeles, Calif. *1733 W. 80th St.*
STEIMLEY, L. L., Ph.D. (Illinois) Instr., Univ. of Illinois, Urbana, Ill.
STEININGER, EDITH, A.M. (Kansas) Instr., Jr. Coll., Coffeyville, Kans. *912 Willow St.*
STEIRNAGLE, W. M., A.B. (Indiana) United Film Industries, New York, N. Y. *535 Fifth Ave.*
STELSON, Asst. Prof. H. E., Ph.D. (Iowa) Kent State Coll., Kent, Ohio.
STEPHENS, Asst. Prof. EUGENE, M.S. (Washington Univ.) Washington Univ., St. Louis, Mo. *5863 Bartmer Ave.*
STEPHENS, R. C., Ph.D. (Iowa) Instr., Knox Coll., Galesburg, Ill.
STEPHENS, Prof. R. P., Ph.D. (Johns Hopkins) Univ. of Georgia, Athens, Ga.
STETSON, Prof. J. M., Ph.D. (Princeton) Coll. of William and Mary, Williamsburg, Va.
STEVENS, W. R., A.B. (George Washington) Meteorologist, U. S. Weather Bureau, Washington, D. C.
STEVENSON, Asso. Prof. GUY, Ph.D. (Illinois) Univ. of Louisville, Louisville, Ky.
STEWART, I. D., A.B. (Muskingum) Instr., Whitman Coll., Walla Walla, Wash. *424 Boyer Ave.*
STEWART, J. K., M.S. (West Virginia) Grad. Asst., West Virginia Univ., Morgantown, W. Va.
STOKES, ELLEN C., A.M. (Brown) Instr., State Coll. for Teachers, Albany, N. Y. *31 Hampton Ave., Schenectady, N. Y.*
STOKES, E. LOUISE, Ed.M. (Harvard) Teacher, Virginia State Coll., Ettrick, Va.
STONE, JOSEPHINE, A.M. (Peabody) Teacher, Athens Coll., Athens, Ala.
STONE, Prof. ORMOND, A.M. (Old Univ. of Chicago) Retired, Astr., Univ. of Virginia, Charlottesville, Va. *Clifton Station, Fairfax Co., Va.*
STONE, Asso. Prof. R. B., A.M. (Harvard) Purdue Univ., W. LaFayette, Ind. *615 Russell St.*
STONER, P. W., M.S. (California) Teacher, High School, Pasadena, Calif. *2131 Spaulding Pl.*
STOUFFER, Prof. E. B., Ph.D. (Illinois) Univ. of Kansas, Lawrence, Kans.
STOUT, C. E., A.M. (Wisconsin) Head of Dept., Genl. Motors Inst. of Tech., Flint, Mich. *1917 Monteith St.*
STOWELL, Prof. C. J., Ph.D. (Illinois) McKendree Coll., Lebanon, Ill.
STRATTON, Prof. W. T., Ph.D. (Washington) State Agric. Coll., Manhattan, Kans.

STREATOR, G. W., A.M. (Western Reserve) Instr., Bennett Coll. for Women, Greensboro, N. C. *949 E. Washington St.*
STREET, R. E. Student, Rensselaer Poly. Inst., Troy, N. Y. *16 Elmgrove Ave.*
STREETMAN, FLORA M., A.M. (Rice) 2616 Louisiana St., Houston, Tex.
STROM, Prof. C. W., Ph.D. (Illinois) Luther Coll., Decorah, Iowa.
STRONG, Prof. CORA, A.M. (Michigan) North Carolina Coll., Greensboro, N. C.
SUESMAN, W. P., LL.B. (Lake Forest) 241 Weybosset St., Providence, R. I.
SUFFA, Prof. MARY C., A.M. (Brown) Elmira Coll., Elmira, N. Y.
SULLIVAN, RUSSELL, A.B. (Yale) 1431 N. Meridian St., Indianapolis, Ind.
SWANSON, A. G., A.M. (Nebraska) 314 E. Dartmouth St., Flint, Mich.
SWARTZEL, Prof. K. D., M.S. (Ohio State) Univ. of Pittsburgh, Pittsburgh, Pa. *4360 Center Ave.*
SWEAZEY, Prof. G. B., A.M. (Wabash) Physics and Applied Math., Westminster Coll., Fulton, Mo.
SWEET, E. F. 117 E. Main St., Phelps, N. Y.
SWEET, H. L. Instr., Phillips Exeter Acad., Exeter, N. H.
SWIFT, Prof. ELIJAH, Ph.D. (Göttingen) Univ. of Vermont, Burlington, Vt. *415 S. Willard St.*
SYNGE, Prof. J. L., Sc.D. (Dublin) Univ. of Toronto, Toronto, Ont., Can.

TABER, G. H. 4114 Bigelow Blvd., Pittsburgh (13), Pa.
TALIAFERRO, Prof. CARRIE B., A.M. (Columbia) State Teachers Coll., Farmville, Va.
TALIAFERRO, Prof. T. H., Ph.D. (Johns Hopkins) Dean, Coll. of Arts and Sciences, Univ. of Maryland, College Park, Md.
TAMARKIN, Prof. J. D., Ph.D., M.A.M. (Petrograd) Brown Univ., Providence, R. I.
TAN, Prof. V. A., Ph.D. (Chicago) Univ. of the Philippines, Manila, P. I.
TANGJERD, H. I., A.B. (St. Olaf Coll.) Instr., St. Olaf Coll., Northfield, Minn.
TANZOLA, J. J., A.M. (Columbia) Instr., Cooper Union, New York, N. Y. *2041 Watson Ave. Bronx.*
TAPPAN, Prof. A. HELEN, Ph.D. (Cornell) Dean of Women, Western Coll., Oxford, Ohio.
TARTLER, ALEXANDER, A.B. (Pennsylvania) Instr., Drexel Inst., Philadelphia, Pa. *32nd and Chestnut Sts.*
TATE, JENNIE L., A.M. (Wisconsin) Head of Dept., McMurry Coll., Abilene, Tex.
TAYLOR, Prof. EUGENE, A.M. (DePauw) Univ. of Idaho, Moscow, Ida.
TAYLOR, Prof. E. H., Ph.D. (Harvard) State Teachers Coll., Charleston, Ill.
TAYLOR, Prof. F. J., A.B. (St. Thomas) St. Thomas Coll., St. Paul, Minn.
TAYLOR, Prof. J. H., Ph.D. (Chicago) George Washington Univ., Washington, D. C.
TAYLOR, Prof. J. S., Ph.D. (California) Univ. of Pittsburgh, Pittsburgh, Pa. *103 Alumni Hall.*
TAYLOR, Prof. MILDRED E., Ph.D. (Illinois) Head of Dept., Mary Baldwin Coll., Staunton, Va.
TAYLOR, Prof. W. E., Ph.D. (Syracuse) Syracuse Univ., Syracuse, N. Y. *822 Irving Ave.*
TAYLOR, Prof. W. H., Ph.D. (Iowa) Alabama Coll., Montevallo, Ala.
THECLA, Sister MARY, Ph.D. (Fordham) Teacher, Queen of All Saints High School, Brooklyn, N. Y. *315 Clinton Ave.*
THEOBALD, Prof. JOHN, A.B. (Columbia Coll.), S.T.B. (Catholic Univ.) Columbia Coll., Dubuque, Iowa.
THIESMEYER, MILDRED G., A.M. (Columbia) Teacher, Hunter Coll. High School, New York, N. Y. *81 Anderson Ave., Scarsdale, N. Y.*
THOM, ADELA M., A.M. (Chicago) Elgin, Ill.
THOMAS, Prof. C. F., A.B. (Amherst) Case School of Appl. Sc., Cleveland, Ohio.
THOMAS, Prof. EVAN. Coll. of Eng., Univ. of Vermont, Burlington, Vt. *187 Loomis St.*
THOMAS, Asst. Prof. R. W., M.S. (Washington and Jefferson) Washington and Jefferson Coll., Washington, Pa. *333 Wilson Ave.*
THOMAS, Asso. Prof. T. Y., Ph.D. (Princeton) Princeton Univ., Princeton, N. J. *Fine Hall*
THOME, W. J., C.E. (Mich. State Coll.) 14911 Fairfield Ave., Detroit, Mich.
THOMPSON, Asso. Prof. E. L., Ph.D. (Chicago) Texas Tech. Coll., Lubbock, Tex.
THOMPSON, EVELYN R., A.M. (Columbia) Teacher, Western High School, Washington, D. C.
THOMPSON, Asst. Prof. HELEN, Ph.D. (Columbia) Research Assoc. in Biometry, Clinic of Child Development, New Haven, Conn. *52 Hillhouse Ave.*
THOMPSON, J. E., A.M. (Columbia) Instr., Pratt Inst., Brooklyn, N. Y. *260 Washington Ave.*
THOMPSON, Prof. MIRIAM A., A.M. (North Carolina) Registrar, Limestone Coll., Gaffney, S. C.
THOMSEN, H. IVAH, Ph.D. 1928 Mt. Royal Terrace, Baltimore, Md.

THOMSON, J. F., M.S. (Union Coll.) Instr., Univ. of Michigan, Ann Arbor, Mich. *1014 Cornwell Ave.*
THORNTON, H. B., A.M. (Cincinnati) Head of Dept., Sumner Jr. Coll., Kansas City, Kans. *418 Adams St., Jefferson City, Mo.*
THORNTON, Prof. W. M., LL.D. (Hampden-Sidney) Applied Math., Univ. of Virginia, University, Va.
THORP, ELLA A. M., A.B. (Minnesota) Instr., Univ. of Minnesota, Minneapolis, Minn. *656 Jefferson St. N. E.*
TIENZO, Asst. Prof. TELESFORO, M.S. (Chicago) Univ. of the Philippines, Manila, P. I. *Dept. of Math.*
TILLEY, Asst. Prof. ARTHUR, M.S. (New York Univ.) Washington Square Coll., New York Univ., New York, N. Y.
TINNEY, Prof. J. C., M.S. (Chicago) Bishop Coll., Marshall, Tex.
TITSWORTH, Mrs. H. L., A.B. (Tulane) Fellow, Newcomb Coll., New Orleans, La. *2320 Nashville Ave.*
TITSWORTH, Prof. W. A., M.S. (Wisconsin) Head of Dept., Alfred Univ., Alfred, N. Y.
TITT, Prof. H. G., A.M. (Michigan) Huron Coll., Huron, S. D. *959 Ohio Ave. S. W.*
TITUS, C. M., A.M. (Stanford) Instr., Univ. Farm School, Davis, Calif.
TOCHER, R. B. Student, Hobart Coll., Geneva, N. Y. *711 S. Main St.*
TOLAR, Prof. M. B., A.M. (Kentucky) Head of Dept., Fenn Coll., Cleveland, Ohio.
DETOLEDO, Prof. L. O. Univ. of Madrid, Madrid, Spain. *Velasques 28-3°, Facultad de Ciencias.*
TOOPS, Prof. H. A., Ph.D. (Columbia) Psych., Ohio State Univ., Columbus, Ohio.
TORRANCE, C. C., A.M. (Cornell) Instr., Cornell Univ., Ithaca, N. Y. *Dept. of Math.*
TORREY, Asst. Prof. MARIAN M., Ph.D. (Cornell) Goucher Coll., Baltimore, Md. *On leave 1931–32, 238 Williams St., Providence, R. I.*
TOUTON, Prof. F. C., Ph.D. (Columbia) Vice-Pres. and Dir. of Educational Program, Univ. of Southern California, Los Angeles, Calif.
TOWNSEND, Prof. E. J., Ph.D. (Göttingen) Emeritus, Univ. of Illinois, Urbana, Ill. *510 John St.*
TRACEY, Asso. Prof. J. I., Ph.D. (Johns Hopkins) Yale Univ., New Haven, Conn. *84 McKinley Ave.*
TRACY, SARAH E., B.L. (Swarthmore) Teacher, John Burroughs School, Clayton, Mo. *7918 Kingsbury Blvd., St. Louis, Mo.*
TREMBLAY, Prof. ALTHÉOD, Higher Math., Laval Univ., Quebec, Can. *472 St. Francois St.*
TREVOR, Prof. J. E., Ph.D. (Leipzig) Thermodynamics, Cornell Univ., Ithaca, N. Y.
TRIPP, Prof. M. O., Ph.D. (Columbia) Wittenberg Coll., Springfield, Ohio.
TUCKER, B. A., A.B. (Mississippi) Southeastern La. Coll., Hammond, La. *Box 726.*
TURNER, Prof. A. B., Ph.D. (Pennsylvania) Coll. of the City of New York, New York, N. Y. *245 N. Mountain Ave., Montclair, N. J.*
TURNER, Prof. BIRD M., Ph.D. (Bryn Mawr) West Virginia Univ., Morgantown, W. Va. *107 High St.*
TURNER, Asso. Prof. J. S., Ph.D. (Chicago) Iowa State Coll., Ames, Iowa. *2514 Knapp St.*
TYLER, A. C., A.B. (Princeton) Headmaster, Providence Country Day School, East Providence, R. I. *Box 106.*
TYLER, H. W., Ph.D. (Erlangen) Consultant, Liby. of Congress; Genl. Secy., Amer. Asso. of Univ. Professors, Washington, D. C. *26 Jackson Pl.*
TYLER, Asst. Prof. JOHN. U. S. Naval Acad., Annapolis, Md. *3 Southgate Ave.*

UHLER, Asso. Prof. H. S., Ph.D. (Johns Hopkins) Physics, Yale Univ., New Haven, Conn. *108 Thornton St., Hamden, Conn.*
ULRICH, F. E., A.M. (Harvard) Instr., Union Coll., Schenectady, N. Y. *37 Ray St.*
UNDERHILL, Asso. Prof. A. L., Ph.D. (Chicago) Univ. of Minnesota, Minneapolis, Minn.
UNDERWOOD, P. H. Ball High School, Galveston, Tex. *2527 Ave. I.*
UNDERWOOD, Asso. Prof. R. S., Ph.D. (Chicago) Texas Tech. Coll., Lubbock, Tex.
UNSELD, G. P., A.M. (Colorado) Physics, W. Side High School, Salt Lake City, Utah. *1359 Glenmore St.*
UPTON, Prof. C. B., A.M. (Columbia) Teachers Coll., Columbia Univ., New York, N. Y.
URNER, S. E., Ph.D. (Harvard) Instr., Jr. Coll., Los Angeles, Calif. *2129 Holly Dr.*

VAN ARNAM, R. N., M.S. (Cornell) Asst., Math. and Astr., Lehigh Univ., Bethlehem, Pa. *418 N. New St.*
VAN BUSKIRK, Prof. H. C., Ph.B. (Cornell) California Inst. of Tech., Pasadena, Calif. *390 S. Holliston Ave.*
VAN DEUSEN, DOROTHY H., B.S. in Eng. (Michigan) Teacher, High School, Battle Creek, Mich. *261 Manchester St.*

VANDIVER, Asso. Prof. H. S. Univ. of Texas, Austin, Tex.
VAN FLEET, G. S., A.M. (Michigan) Asst. Actuary, American Natl. Life Ins. Co., Galveston, Tex.
VANHEE, LOUIS, D.D., Jesuit Father. 11 Rue des Récollets, Louvain, Belgium.
VAN HORNE, R. N., Ph.B. (Morningside) Morningside Coll., Sioux City, Iowa. *1501 Sioux Trail.*
VAN ORSTRAND, C. E., M.S. (Michigan) Geophysicist, U. S. Geol. Survey, Washington, D. C. *1667 31st St., N.W.*
VAN VELZER, Prof. C. A., Ph.D. (Hillsdale) Carthage Coll., Carthage, Ill. *903 Buchanan St.*
VAN VLECK, Prof. E. B., Ph.D. (Göttingen) Emeritus, Univ. of Wisconsin, Madison, Wis. *519 N. Pinckney St.*
VASS, J. I., A.M. (Northwestern) Instr., Univ. of Wisconsin, Extension Div., Milwaukee, Wis. *623 W. State St.*
VEATCH, Asst. Prof. R. W., A.M. (Northwestern) Univ. of Tulsa, Tulsa, Okla.
VEBLEN, Prof. OSWALD, Ph.D. (Chicago) Princeton Univ., Princeton, N. J.
VEDDER, Prof. J. N., A.M. Union Coll., Schenectady, N. Y.
VEHSE, Asst. Prof. C. H., M.S. (Brown) West Virginia Univ., Morgantown, W. Va.
VIRTS, R. O., A.M. (Indiana) Teacher, High School, Ft. Wayne, Ind. *4746 Stratford Rd.*
VIVIAN, ROXANA H., Ph.D. (Pennsylvania) 66 Milton Rd., Rye, N. Y.

WAGNER, Asso. Prof. C. C., Ph.D. (Michigan) Pennsylvania State Coll., State College, Pa. *122 S. Atherton St.*
WAGNER, E. H., A.M. (Illinois) 1709 Jackson Ave., Ann Arbor, Mich.
WAGNER, Prof. P. S., Ph.D. (Johns Hopkins) Lebanon Valley Coll., Annville, Pa.
WAHLIN, Prof. G. E., Ph.D. (Yale) Univ. of Missouri, Columbia, Mo. *1401 Anthony St.*
WALDEN, Prof. E. E., A.M. (Colorado) Lambuth Coll., Jackson, Tenn.
WALDER, O. E., A.M. (Nebraska) Instr., South Dakota Coll., Brookings, S. D.
WALKER, Asso. Prof. EVELYN, Ph.D. (Columbia) Hunter Coll., New York, N. Y. *695 Park Ave.*
WALKER, Asst. Prof. HELEN M., Ph.D. (Columbia) Educ. Statistics, Teachers Coll., Columbia Univ., New York, N. Y.
WALKER, L. C., A.M. (Stanford) Ceresco, Nebr.
WALKER, R. J., B.S. (Carnegie Inst. of Tech.) Grad. Student, Princeton Univ., Princeton, N. J.
WALLIS, W. J., A.M. (Columbian Univ.), LL.B. (George Washington) Head of Dept., High Schools, Washington, D. C. *Central High School.*
WALSH, C. M., A.B. (Harvard) Bellport, L. I., N. Y.
WALSH, Asso. Prof. J. L., Ph.D. (Harvard) Harvard Univ., Cambridge, Mass. *547 Widener Liby.*
WALTER, ARTHUR, A.M. (Stanford) City Supt. of Schools, Salinas, Calif.
WALTER, R. M., A.M. (Columbia) Instr., New Jersey Coll. for Women, New Brunswick, N. J.
WALTERS, E. L., B.S. (Washington and Jefferson) Grad. Asst., Syracuse Univ., Syracuse, N. Y. *208 Westminster Ave.*
WALTON, Asst. Prof. T. O., M.S. (Chicago) Kalamazoo Coll., Kalamazoo, Mich.
WALTZ, Asst. Prof. A. K., Ph.D. (Cornell) Clarkson Coll., Potsdam, N. Y. *52 Bay St.*
WAPPLE, Prof. A. R., A.M. (California) Southwestern Univ., Georgetown, Tex.
WARD, ETHEL RUTH, A.M. (North Carolina) Instr., Math. and Chem., State Coll. for Women, Columbus, Miss. *Box 1546, College Sta.*
WARD, Asst. Prof. L. E., Ph.D. (Harvard) Univ. of Iowa, Iowa City, Iowa. *120 Physics Bldg.*
WARD, Asst. Prof. MORGAN, Ph.D. (Calif. Inst. of Tech.) California Inst. of Tech., Pasadena, Calif.
WARNER, I. N., B.S. (Chicago) State Teachers Coll., Platteville, Wis.
WARREN, Asst. Prof. E. C., B.S. (Mass. Inst. of Tech.) Colby Coll., Waterville, Me. *28 Winter St.*
WARREN, Prof. L. A. H., Ph.D. (Chicago) Univ. of Manitoba, Winnipeg, Man., Can.
WASHBURNE, A. C., Grad. (U. S. Milit. Acad.) Actuary, Berkshire Life Ins. Co., Pittsfield, Mass.
WATKEYS, Prof. C. W., A.M. (Harvard) Univ. of Rochester, Rochester, N. Y. *287 Dartmouth St.*
WATKINS, EMILY H., A.M. (Teachers Coll., Columbia) Instr., North Carolina Coll. for Women, Greensboro, N. C.
WATT, Asst. Prof. MARTHA W., A.M. (Columbia) Wheaton Coll., Norton, Mass. *2144 Broad St., Providence, R. I.*

WATTS, C. B., A.B. (Indiana) Astronomer, U. S. Naval Observ., Washington, D. C.
WEAR, Prof. L. E., Ph.D. (Johns Hopkins) California Inst. of Tech., Pasadena, Calif. *68 S. Grand Oaks Ave.*
WEAVER, Prof. J. H., Ph.D. (Pennsylvania) Ohio State Univ., Columbus, Ohio. *Hilliard, Ohio.*
WEAVER, Prof. WARREN, Ph.D. (Wisconsin) Univ. of Wisconsin, Madison, Wis. *1852 Summit Ave.*
WEBBER, Prof. W. P., Ph.D. (Cincinnati) Louisiana State Univ., Baton Rouge, La.
WEBER, W. W., A.M. (Georgia) Dean and Prof. of Math., Lander Coll., Greenwood, S. C. *Box 111.*
WEBSTER, Asso. Prof. LOUISA M., M.S. (New York Univ.) Hunter Coll., New York, N. Y. *218–41–99 Ave., Queens Village, L. I., N. Y.*
WECHSLER, A. L., A.M. (Columbia) Instr., Univ. Extension, Columbia Univ., New York, N. Y. *Apt. No. 712, 27 W. 72nd St.*
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ZARISKI, OSCAR, Ph.D. (Univ. of Rome) Associate, Johns Hopkins Univ., Baltimore, Md. *Dept. of Math.*
ZELDIN, Asst. Prof. S. D., Ph.D. (Clark) Mass. Inst. of Tech., Cambridge, Mass.
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BERKELEY. Bernstein, Haskell, Irwin, Keeler, Lehmer, Levy, McCarty, McDonald, Noble, Powelson, Putnam, Sperry, Williams, Wong, Woo.
CHICO. Iloff.
CLAREMONT. Berry, Jaeger, Russell.
DAVIS. Titus.
FRESNO. Morris.
FULLERTON. Ernsberger, Reynolds.
GLENDALE. Bolton.
HOLLYWOOD. Entz.
LA JOLLA. McEwen.
LONG BEACH. Lodwick.
LOS ANGELES. Allen, Ames, Bell, Campbell, Collier, Daus, Garver, Gaver, Glazier, Hedrick, Hill, Hunt, James, McClellan, Mason, Orange, Sherwood, Showman, Steed, Touton, Urner, Whyburn, Willett, Worthington.
MILLS COLLEGE. Alderton.
MODESTO. Pobanz.
MT. HAMILTON. Jeffers.
PALO ALTO. Hoskins, Stager.
PASADENA. Bateman, Bell, Birchby, Meek, Michal, Millikan, Stoner, Van Buskirk, Ward, Wear, Wolfe.
REDLANDS. Albert, Keith.
SALINAS. Walter.
SAN DIEGO. Gleason, Klauber, Livingston.
SAN FRANCISCO. Ivanoff, Libby.
SANTA ANA. Whiting.
SANTA BARBARA. Fenner.
SANTA MARIA. Funk.
STANFORD UNIVERSITY. Blichfeldt, Eells, Green, Lehmer, Moreno.
STOCKTON. Corbin.
TAFT. Robb.
WHITTIER. Hadley, Skarstedt.

CANADA. (37)

CALGARY. Young.
EDMONTON SOUTH. Campbell, Cook, Sheldon.
HAMILTON. Findlay.
KINGSTON. Gummer, Johnston, Matheson, Miller.
LENNOXVILLE. Home, Richardson.
LONDON. Kingston.
MONTREAL. MacLean, Murray, Pelletier.
NIAGARA FALLS. Scharf.
OTTAWA. Dube, Henroteau.
QUEBEC. Savary, Tremblay.
SACKVILLE. McEwen.
SASKATOON. Dines, Ling.
TORONTO. Beatty, De Lury, Fields, Pounder, Roseburgh, Synge.
VANCOUVER. Buchanan, Jordan.
VICTORIA. Gage.
WINNIPEG. Milne, Riter, Warren, Wilson.
WOLFVILLE. Jeffery.

CANAL ZONE. (1)

BALBOA HEIGHTS. Judd.

COLORADO. (30)

BOULDER. Britton, De Long, Hacker, Hutchinson, Jekel, Kempner, Kendall, Lester, Light, McMaster, Nelson, Rainville.
CANON CITY. McNatt.
COLORADO SPRINGS. Folk, Lovitt, Sisam.
DENVER, Carmichael, Gorrell, Lewis, McGinley, Odell, Recht, Risley, Rote, Sabin.
FORT COLLINS. Clark, Macdonald.
GOLDEN. Everett, Fitterer.
GREELEY. Finley.

CONNECTICUT. (37)

GREENWICH. Burney.
HARTFORD. Andrews, Dadourian, Davis, Elston, B. D. Flynn, J. D. Flynn, Mitchell, Welling.
MIDDLETOWN. Arnold, Camp, Howland.
MILFORD. Burgess, Rosenbaum.
NEW HAVEN. Barney, E. W. Brown, Church, Fisher, Fox, Kovarik, Longley, Miles, Moore, Ore, Pierpont, P: F. Smith, Thompson, Tracey, Uhler, Whittemore, Wilson.

NEW LONDON. Dimick, Leib, Shover.
STORRS. Cheney.
WATERBURY. Pine.
WEST HAVEN. Shook.

CUBA. (1)

HAVANA. Corral y Alemán.

DELAWARE. (7)

DOVER. Short.
NEWARK. Harding, Harter, McDougle, Rees.
WILMINGTON. Gardner, R. W. Jones.

DISTRICT OF COLUMBIA. (47)

BROOKLAND. Landry.
WASHINGTON. Adams, Arnaud, Ashmun, Avers, Bauer, Blake, Braun, Burley, Claire, Cox, Darling, Duerksen, Edmonston, English, Ewin, Federico, Goldberg, Gosnell, Hamilton, Johnston, Keulegan, Kullback, Lambert, Lennahan, Mangold, Mears, Querfeld, Ramler, Rice, Richmond, Roos, Scheier, Shenton, Sinkov, Stevens, Taylor, Thompson, Tyler, Van Orstrand, Wallis, Watts, Weida, Wernicke, Woodard, Woolard, Zoch.

FLORIDA. (13)

DE LAND. Faulkner.
FORT PIERCE. Bullard.
GAINESVILLE. Dostal, Kokomoor, Messick, Pirenian, Simpson, Wilson.
LAKELAND. Cox.
ORMOND BEACH. Palmié.
TALLAHASSEE. Larson, E. R. Smith.
WINTER PARK. Weinberg.

GEORGIA. (21)

ATHENS. Barrow, Cumming, Hill, Stephens,
ATLANTA. Fulmer, Hefner, Hook, Morton, Patton, Skiles, D. M. Smith, Wood.
DECATUR. Field, Gaylord, Robinson.
DEMOREST. Rogers.
EMORY UNIVERSITY. Messick.
FORSYTH. Plymale.
LA GRANGE. Bailey.
MACON. Holder.
ROME. Hightower.

HAWAII. (1)

HONOLULU. Donaghho.

IDAHO. (2)

CALDWELL. Rankin.
MOSCOW. Taylor.

ILLINOIS. (126)

BASCO. Holloway.
BLOOMINGTON. Hunt.
BLUFFS. Carter.
CARLINVILLE. Renner.
CARTHAGE. Van Velzer.
CHAMPAIGN. Moore, Rogers.
CHARLESTON. Taylor.
CHICAGO. Barnard, Bartky, Bay, Bibb, Bliss, Bower, G. M. Brown, Burrows, Butler, Campbell, Christman, Cobb, Davis, Dickson, Dunford, Ettinger, Everett, Georges, Gerst, Graves, Haggard, Jarrett, Kanies, Kinney, Krathwohl, Kurzin, Lane, Lange, Laves, Logsdon, Lunn, MacMillan, McShane, Moore, Moulton, Nicolet, Nixon, Nyberg, Pettersen, Pyke, Reid, Roberts, Roeser, Schweitzer, Slaught, Spencer, Stafford, Stauffer, Young.
CICERO. Richards.
DECATUR. Kiefer.
DE KALB. Parson.
ELGIN. Thom.
EUREKA. Newson.
EVANSTON. Curtiss, Feltges, Garabedian, Griffiths, Holgate, Moulton, Newell, Simmons, Wescott, Wood.
FREEPORT. Martin, Mensenkamp.
GALESBURG. Heren, Sellew, Stephens.
GODFREY. Bromwell.
GURNEE. Johnston.
JACKSONVILLE. Anderson, Miller.
LAKE FOREST. Curtis.
LA SALLE. Rabe, Carus.
LEBANON. Stowell.
LINCOLN. Balof, Denny.
MACOMB. Ginnings, Schreiber.
MAYWOOD. Hildebrandt.
MONMOUTH. Beveridge, Winbigler.
NORMAL. Atkin, Flagg, Mills.
OAK PARK. Escott.
PEORIA. Comstock, Gault.
RIVER FOREST. Dobbin.
ROCKFORD. McGavock.
ROCK ISLAND. Cederberg.
SANDWICH. Rumney.
TAYLORVILLE. Dappert.
TUSCOLA. Wolever.
URBANA. Armstrong, Bailey, Bower, D. M. Brown, Carmichael, Coble, Crathorne, Emch, Grant, Hazlett, Levy, Lytle, Merrill, Miles, Miller, Peters, Rumsey, P. K. Smith, Steimley, Townsend, Young.
WHEATON. Hillard.

INDIANA. (65)

BLOOMINGTON. Davis, Hanna, Hennel, Moore, Rothrock, Williams, Wolfe.
COLUMBIA CITY. Knisely.
CRAWFORDSVILLE. Carscallen.
CULVER. Adkins.
DANVILLE. Cole.
EARLHAM. Long.
EAST CHICAGO. Darragh, Kellam.
FORT WAYNE. d'Unger, Jenkins, Paxton, Reising, Virts.
FRANKLIN. Heath.
GEORGETOWN. Kelly.
GOSHEN. Lehman.
GREENCASTLE. Arnold, Edington, Greenleaf.
HANOVER. Meyer.
INDIANAPOLIS. Aley, Banes, Bowersox, Johnson, Lutz, Sullivan.
LAFAYETTE. Marshall, Mason, Miller.
MARION. West.
MUNCIE. Edwards, Shiveley.

North Manchester. Dotterer.
Notre Dame. Caparó, McCue, Maurus.
Oakland City. Jordan.
Scircleville. Orr.
Richmond. Grant.
Terre Haute. Kennedy, Pollock, Shriner, Sousley.
Valparaiso. Copp.
Vevay. Haskell.
West LaFayette. Black, Bolks, Doan, Graves, Hadley, Happell, Hazard, Hodge, Hughes, Klinger, Little, Long, Robbins, Stone.

Iowa. (57)

Ames. Brandner, Colpitts, Daniells, Fleming, Gouwens, Herr, J. V. McKelvey, M. M. McKelvey, Roberts, Robertson, E. R. Smith, Snedecor, Turner.
Britt. Day.
Cedar Falls. Condit, Kearney, Wester.
Cedar Rapids. Coffin, Yothers.
Davenport. Ries.
Decorah. Strom.
Des Moines. Corey, Garnett, Neff.
Dubuque. Theobald, Zimmerman.
Fairfield. Roberts.
Fayette. Deming.
Forest City. Mundhjeld.
Grinell. Bailey, McClenon, Rusk.
Hopkinton. Earhart.
Indianola. Emmons.
Iowa City. F. E. Baker, R. P. Baker, Chittenden, Conkwright, Constantine, Fischer, Reilly, Rietz, Ward, Woods, Wylie.
Le Mars. Blue.
Mount Vernon. McGraw, Moots.
Odebolt. Wilmer.
Oskaloosa. Sherman.
Pella. Evers.
Sioux City. Graber, Gwinn, Olson, Van Horne.
Waverly. Brezler.
Wellman. Kreth.

Kansas. (52)

Atchison. Pretz.
Baldwin. Garrett.
Coffeyville. Steininger.
El Dorado. Wrestler.
Emporia. Peterson.
Hays. Colyer, Zinszer.
Hesston. Driver.
Independence. Bell.
Kansas City. Dougherty, Thornton.
Lawrence. Ashton, Babcock, Black, Jordan, Mitchell, G. W. Smith, Stouffer, Wheeler, Willey.
Lindsborg. Marm.
Manhattan. Andrews, Babcock, Hyde, Janes, Lewis, Lyons, Mossman, Ollivier, Porter, Remick, Stratton, White.
McPherson. Arnett.
Newton. Richert.
Ottawa. Bennett, Loewen.
Pittsburg. Hill, Shirk.
St. Marys. Quinn.
Salina. Fahnestock, McCain, Ploenges.
Sterling. Bell.
Topeka. Harshbarger, Householder, McLatchey.
Wichita. Hoare, Longenecker, Mendenhall, Reagan.
Winfield. Myers.

Kentucky (31)

Berea. Hutcherson, Pugsley.
Bowling Green. Johnson, Yarbrough.
Campbellsville. Lyon.
Danville. Fehn.
Georgetown. Hatfield.
Jackson. Fremd.
Lexington. Allison, Baxter, Boyd, Cohen, Davis, Downing, Hendricks, Latimer, LeStourgeon, Maney, Mathis, Park, Pence, Rees.
Louisville. Anselm, Bullitt, Hill, Moore, Paulinus, Simester, Stevenson.
Murray. Carman.
Richmond. Park.

Louisiana. (25)

Baton Rouge. Nichols, O'Quinn, Sanders, H. L. Smith, Webber.
Clinton. Petty
Columbia. Redditt.
Hammond. Tucker.
Natchitoches. Blair, Killen, Maddox.
New Orleans. Anderson, Buchanan, Dinwiddie, Duren, Frankenbush, Gentry, Many, Menuet, Monasterio, Spencer, Titsworth, Weiss.
Pineville. C. D. Smith.
Shreveport. Maizlish.

Maine (12)

Brunswick. Hammond, Holmes, Moody.
Houlton. Morse.
Lewiston. Ramsdell, Wilkins.
Orono. Bryan, Hart, Jordan, Schultz.
Waterville. Ashcraft, Warren.

Maryland (41)

Aberdeen. Dederick.
Annapolis. Bingley, Bramble, Capron, Clayton, Clements, Dillingham, Kells, Leiper. Lyle, Rawlins, Root, Scarborough, Tyler.
Baltimore. Aitchison, Bacon, Bassler, Cohen, Harry, Lewis, Morrill, Murnaghan, Reed, Reynolds, Richeson, Thomsen, Torrey, Whyburn, Williamson, Zariski.
Cheltenham. Hartnell.
College Park. Alrich, Gwinner, Spann, Taliaferro, Yates.
Cumberland. Hart.
Emittsburg. Burke.
Frederick. Brown.
Port Deposit. Haviland.
Roland Park. Morrow.

Massachusetts. (98)

Amesbury. Dame.

AMHERST. Esty, Moore, Porter.
ANDOVER. Newton.
ATTLEBORO. Holt.
BELMONT. Douglass, Rutledge.
BOSTON. Andrew, Bruce, Garabedian, Gould, Laurentine, Leavens, Littauer, Mode, Schroeder, Spear, Wilson.
BROOKLINE. Miller.
CAMBRIDGE. Bailey, Ball, Beatley, Birkhoff, Bradley, Brown, Coolidge, Cooper, Coral, Crum, Franklin, Gaylord, Graustein, Huntington, Kellogg, Kennelly, Littauer, Longley, Moore, Morse, Osgood, Passano, Peterson, Phillips, Price, Rice, Robinson, Seidel, Walsh, Widder, Wilson, Woods, Wright, Zeldin.
DANVERS. Majella.
DORCHESTER. Davis, Heins, Quigley.
EVERETT. Bryant.
GLOUCESTER. MacNutt.
GROTON. Nash.
LOWELL. Aurelius.
LYNN. Evans.
MEDFORD. Miller.
NATICK. Willis.
NORTHAMPTON. Benedict, McCoy, Munroe, Rambo, Wood.
NORTH BROOKFIELD. Kimball.
PETERSHAM. Moriarty.
PITTSFIELD. Washburne.
SOUTH HADLEY. Anderton, Doak, Martin.
TUFTS COLLEGE. Mergendahl, Ransom.
WELLESLEY. Copeland, Doughty, Hall, Merrill, C. E. Smith, Stark, Young.
WILLIAMSTOWN. Agard, Dorwart, Hardy, Wells.
WOLLASTON. Dennison.
WORCESTER. Brown, Gay, Lepeshkin, Melville, Morley, Rice, Wheeler, Williams.

MICHIGAN. (73)

ALBION. Ingalls, Sleight.
ALMA. Clack.
ANN ARBOR. Aberle, Anning, Ayres, Baten, Bradshaw, Coe, Corliss, Craig, Elder, P. Field, S. E. Field, Ford, Getchell, Hildebrandt, Hopkins, Karpinski, Kazarinoff, Love, Nyswander, Peterson, Raiford, Rainich, Rood, Rouse, Running, Schorling, Thomson, Wagner, Weinberger, Wilder.
BATTLE CREEK. Van Deusen.
BAY CITY. Shellenbarger.
DETROIT. Baldwin, Borgman, Bushyager, Darnell, Folley, Frumveller, Johnson, Johnston, McCarthy, Mullen, Nelson, Paula, Schoonover, Thome.
EAST LANSING. Crowe, Emmons, Grove, Olson, Plant, Powell, Speeker.
FLINT. Stout, Swanson.
HILLSDALE. Herron.
HOUGHTON. Roman.
JACKSON. Field.
KALAMAZOO. Ackley, Blair, Everett, Walton.
MARQUETTE. Spooner.
MOUNT PLEASANT. Richtmeyer.
SPRING ARBOR. M. G. Smith.
YPSILANTI. Barnhill, Erikson, Lindquist, Lyman, Matteson.

MINNESOTA. (43)

COLERAINE. Fisk.
COLLEGEVILLE. Winkelmann.
MANKATO. Robbins.
MINNEAPOLIS. Brink, Brooke, Bussey, Carlson, Dalaker, Erwin, Gibbens, Gunstad, Guttman, Hart, Hartig, Jackson, Jensen, Kirchner, Ness, O'Toole, Priester, Scammon, Schey, Schnell, Shuman, Shumway, Thorp, Underhill, Wilder.
MOORHEAD. Leonard.
NORTHFIELD. Gingrich, Solum, Tangjerd, White.
ST. PAUL. Alice Irene, Chellevold, Kingery, Moench, Morgan, Taylor, Wood.
ST. PETER. Rundstrom.
VIRGINIA. Hancock.
WINONA. Bogard.

MISSISSIPPI. (16)

A. AND M. COLLEGE. Fox, C. D. Smith.
BLUE MOUNTAIN. Hutchins.
CLEVELAND. Hickey.
CLINTON. Price.
COLUMBUS. Ward.
GRENADA. Harris.
HATTIESBURG. Dearman.
HOLLY SPRINGS. McDonald.
JACKSON. Babbitt, McCoy, Mitchell.
STARKVILLE. Edmondson.
UNIVERSITY. Bickerstaff, Rhodes.
WESSON. Felder.

MISSOURI. (48)

CANTON. Ingold.
CAPE GIRARDEAU. Johnson, Knepper.
CARTHAGE. Murto.
CLAYTON. Haertter, Tracy.
COLUMBIA. Callaway, Ingold, Robinson, Wahlin, Westfall.
FAYETTE. Fleet.
FULTON. Christian, Sweazey.
KANSAS CITY. Cutting, Higgins, Luby, Murray, Pierson.
KIRKSVILLE. Cosby, Jamison.
KIRKWOOD. Harris, McFarland.
MAYSVILLE. Saunders.
PARKSVILLE. Wells.
ROLLA. Hinsch.
SEDALIA. Mayer.
SPRINGFIELD. Finkel, H'Doubler.
ST. CHARLES. Karr.
ST. LOUIS. Dunkel, Grummann, Huntington, King, Middlemiss, Muehlman, O'Donnell, Osborn, Rider, Roever, Shannon, Siroky, Stephens, Wilczewski, Young, Zimmerman.
WARRENSBURG. Scarborough.
WEBSTER GROVES. Clarke, Pennell.

MONTANA. (6)

BOZEMAN. Hurst.
HELENA. Canning, Wible.
MISSOULA. Carey, Lennes, Merrill.

NEBRASKA. (23)

BURWELL. Opp.
CERESCO. Walker.
GRAND ISLAND. Anderson.
HASTINGS. McDill.
KEARNEY. Hanthorn.
LINCOLN. Basoco, Brenke, Camp, Candy, Collins, Congdon, Gaba, Howie, Pierce, Runge.
OMAHA. Bettinger, Campbell, Earl, Gunn.
PERU. Hill.
STRANG. Lefever.
WAYNE. Schmeiser.
YORK. Feemster.

NEVADA. (2)

RENO. Allen, Searcy.

NEW HAMPSHIRE. (20)

CONCORD. Conwell.
DURHAM. Bauer, Kichline, Kimball, Slobin, Wilbur.
EXETER. Barber, Butterfield, Sweet.
HANOVER. Beetle, Bill, Brown, Forsyth, Mathewson, Morgan, Perkins, Robinson, Silverman, Wilder, Young.

NEW JERSEY. (39)

BELLEPLAIN. Durell.
BLOOMFIELD. Hussey.
EAST ORANGE. Stanwick.
HIGHTSTOWN. Litterick.
JERSEY CITY. J. P. Smith.
LAWRENCEVILLE. Mikesh.
LEONIA. Gafafer.
MONTCLAIR. Davis, Mallory.
MOORESTOWN. Wood.
MORRIS PLAINS. Johnson.
NEWARK. Conkling.
NEW BRUNSWICK. Bunyan, Meder, Morris, Nelson, Walter, Wilson.
PRINCETON. Adams, Alexander, Dorroh, Eisenhart, Flood, Gillespie, Hille, Kennison, Knebelman, Lefschetz, Levine, Thomas, Veblen, Walker, Wedderburn, Wheeler, Willson.
SUMMIT. MacDonald.
TRENTON. Colliton, Shuster.
WORTENDYKE. F. E. Smith.

NEW MEXICO. (11)

ALBUQUERQUE. Barnhart, Bauer, Fuller, Graham, Harp, MacKay, Newsom.
EAST LAS VEGAS. Rodgers.
MOUNTAINAIR. Conlee.
SILVER CITY. Mickelson.
SOCORRO. Reece.

NEW YORK. (252)

ALBANY. Alice Irene, Beaver, Birchenough, Do Bell, Lester.
ALFRED. Polan, Seidlin, Titsworth.
ALLEGANY. McLaughlin.
ANNANDALE-ON-HUDSON. Garabedian, Phalen.
AURORA. Barbour, Carroll, Hollcroft.
BALDWIN. Grove.
BAYSIDE. Dean.
BELLPORT. Walsh.
BINGHAMTON. Patten.
BRONX. Tanzola.
BROOKLYN. Berry, Bowden, Charosh, Cowles, Deutsch, Fleisher, Fuller, Haas, R. A. Johnson, Karnow, Koch, Kryder, Langman, Lepowsky, Lieber, Locke, Markowitz, Moore, Ruderman, Schuyler, Shorr, Thecla, Thompson, Welkowitz, Whitford, Young.
BUFFALO. Archer, Gehman, Harrington, Montague, Pound, Rice.
CLINTON. Brown, Carruth, Ferry, Fitch, Patterson.
CORONA. Hanson.
DALE. Whaley.
ELMIRA. Suffa, Wright.
FLUSHING. Lehmann, Pruslin.
GENEVA. W. H. Durfee, W. P. Durfee, Hubbs, Starrett, Tocher.
HAMILTON. Aude, A. W. Smith.
HOUGHTON. Brockett.
ITHACA. Boothroyd, Cameron, Carver, Dye, Gillespie, Hadlock, Horsfall, Hurwitz, B. W. Jones, Karapetoff, Lowenstein, Paradiso, Purcell, Randolph, Ranum, Snyder, Torrance, Trevor.
JAMAICA. Barrett.
JORDAN. Howe.
KINDERHOOK. Magee.
NEW YORK. Allen, Allison, Anderson, Archibald, Berger, Bergstresser, Berkeley, Berry, Blair, Bradley, Breckenridge, Breit, Brewster, A. B. Brown, Burdick, Burgess, Bushey, G. A. Campbell, G. C. Campbell, Clark, Cooley, Darkow, Dauenhauer, Doermann, Edmonson, Eisele, Farnum, Feld, Fiske, Fite, Flanders, Foster, Frank, Frankel, Fry, Funkhouser, Gentzler, Gill, Glover, Graham, Griffin, Hall, Harper, Hawkes, Henderson, Hill, Hirsch, Hopper, Hoyt, Hughes, Hurwitz, Hutchinson, Jablonower, Joffe, P. C. Jones, Kunte, Larkin, Linehan, MacGregor, Maiden, Miller, Mirick, Molina, Morehouse, Mullins, Paaswell, Packer, Payne, Pedersen, Penn, Plimpton, Pooler, Post, Pride, Quilty, Raudenbush, Reddick, Rees, Reeve, Ritt, Saurel, Schelkunoff, H. M. Schlauch, W. S. Schlauch, Schub, Seely, Shaw, Shewhart, Siceloff, Simons, Skelding, D. E. Smith, R. F. Smith, R. R. Smith, Spies, Steirnagle, Tilley, Turner, Upton, E. Walker, H. M. Walker, Webster, Wechsler, Weisner, Whitford, Wick, Wilder, Winters, Wood, Wright, Young.
NISKAYUNA. Male.
ONEONTA. Schoonmaker.
PARISH. Church.

PHELPS. Sweet.
POTSDAM. Rowe, Waltz.
POUGHKEEPSIE. Cummings, Wells.
ROCHESTER. Betz, Gale, Harding, Long, Smyth, Watkeys, Welton.
RYE. Vivian.
ST. BONAVENTURE. Nickol.
SCARSDALE. Mac Neish, Thiesmeyer.
SCHENECTADY. Burkett, Lerch, Libman, Morse, Oergel, Poritsky, Snyder, Stokes, Ulrich, Vedder.
STATEN ISLAND. Nordgaard.
SYRACUSE. Campbell, Carroll, Decker, Harwood, Jose, Lindsey, Ryan, Sperry, Taylor, Walters.
TARRYTOWN. Putnam.
TROY. Crockett, McGiffert, Street.
VALLEY STREAM. Henry.
WELLSVILLE. Lish.
WEST POINT. Echols.
YONKERS. Hubert, John, Yanosik.

NORTH CAROLINA. (31)

ASHEVILLE. Peck.
CHAPEL HILL. Browne, Henderson, Hill, Lasley, Linker, Mackie.
CHARLOTTE. O. M. Jones, Woodson.
DAVIDSON. Douglas, Mebane.
DURHAM. Dale, Dressel, Elliott, Hickson, Rankin, Roberts, Robison.
ELON COLLEGE. Amick.
GREENSBORO. Barton, Pegram, Ragsdale, Streator, Strong, Watkins.
GREENVILLE. Graham, ReBarker.
HOT SPRINGS. Meyer.
LOUISBURG. Harris.
MARS HILL. Robinson.
WINGATE. Hendricks.

NORTH DAKOTA. (6)

FARGO. Householder, I. W. Smith.
GRAND FORKS. Leith, Staley.
UNIVERSITY. Hitchcock.
VALLEY CITY. Meyer.

OHIO. (131)

ADA. Fairchild, Whitted.
AKRON. Bender.
ASHLAND. Black.
ATHENS. Borger, Reed.
BEREA. Baur, Dustheimer.
BOWLING GREEN. Mathias, Overman.
BLUFFTON. Hirschler.
CANAL WINCHESTER. Bareis.
CHILLICOTHE. Mathias.
CINCINNATI. Barnett, Brand, Hancock, Hobensack, Justice, Kersten, Kindle, Lubin, Merriman, Moore, Mullings, Rhodes, Salkover, E. S. Smith, Yowell.
CLEVELAND. Baker, Benander, Boyce, O. E. Brown, Burington, Burwell, Focke, Johnson, Jonah, Justin, Morris, Musselman, Nassau, Oldenburger, Sanford, Sauté, Simon, Thomas, Tolar, Trofimov.
COLUMBUS. Alden, Amos, Bamforth, Beatty, Blumberg, Buell, Harmount, Hildner, Horn, M. E. Jones, Kuhn, LaPaz, MacDuffee, Manson, Morris, Radó, Rasor, Rickard, Singer, Toops, Wildermuth.
DAYTON. Hartwick.
DEFIANCE. Caris, MacCullough.
DELAWARE. Crane, Newlin, Rowland.
FINDLAY. Roots.
GAMBIER. Allen, Bumer.
GRANVILLE. Ladner, Peckham, Wiley.
HILLIARD. Weaver.
HIRAM. Clarke, Jerome.
IVORYDALE. Selheimer.
KENT. Manchester, Schaeffer, Stelson.
MARIETTA. Cope, Rea.
MOUNT ST. JOSEPH. Corona.
NEW CONCORD. White.
NORWOOD. Wishard.
OBERLIN. Cairns, Carr, Johnson, Sinclair, Smyth, Yeaton.
OXFORD. Anderson, Erickson, Pollard, Spenceley, Tappan, Wolfe.
PAINESVILLE. Lewis.
ROSS. Haldeman.
SPRINGFIELD. Tripp.
TIFFIN. Pierce.
TOLEDO. Brandeberry, Dancer, Lemme, Mercedes, Winslow.
WESTERVILLE. Glover, Menke.
WILMINGTON. Spinks.
WOOSTER. Knight, Williamson, Yanney.
YELLOW SPRINGS. Dawson, Dwyer.
YOUNGSTOWN. Foard.
ZANESVILLE. Riesbeck.

OKLAHOMA. (23)

ALVA. Hall.
CORDELL. Croom.
MIAMI. Whitney.
MUSKOGEE. Barrick.
NORMAN. Brixey, Court, Duval, Hassler, McFarland, Meacham, Reaves.
SHAWNEE. Short.
STILLWATER. Barnett, Drummond, Flanders, Garretson, Gundersen, H. W. Smith.
TAHLEQUAH. Wyant.
TULSA. Byrd, Howard, Veatch, West.
WEATHERFORD. McCormick.

OREGON. (11)

ALBANY. Ramsey.
CORVALLIS. Beaty, Johnson, Kirkham, Williams.
EUGENE. De Cou, McAlister, Milne.
PORTLAND. Griffin, Merriss, Short.

PANAMA. (1)

PANAMA CITY. Linares.

PENNSYLVANIA. (130)

ANNVILLE. Wagner.
BALA-CYNWYD. Sensenig.
BARNESBORO. Fisanick.
BEAVER FALLS. Cleland, McCormick.
BETHLEHEM. Cairns, Cutler, Ewing, Fort, Latshaw, Rau, Raynor, Reynolds, Shook, Smail, Van Arnam.

BRYN ATHYN. Allen.
BRYN MAWR. Lehr.
BUTLER. Robb.
CALIFORNIA. Foberg.
CARLISLE. Ayres, Landis.
COLLEGEVILLE. Clawson, Manning.
DEVON. Clarke.
EASTON. Hall, Hatch, W. M. Smith.
ERIE. Benedicta, Wells.
GETTYSBURG. Reen.
GROVE CITY. Grimes.
HARRISBURG. Whited.
HAVERFORD. Gummere, Reid, Wilson.
KUTZTOWN. Kunkel.
LANCASTER. Charles, Long.
LARIMER. A. A. Jones.
LATROBE. Seubert.
LEWISBURG. Gold, Lindemann, MacCreadie, Richardson, Youtz.
LINCOLN UNIVERSITY. Wright.
LOCKHAVEN. High, S. J. Smith.
MEADVILLE. Akers, Beisel.
MILLERSVILLE. Seiverling.
NEW WILMINGTON. Freas.
PARADISE. Eshleman.
PHILADELPHIA. Arnold, Bristol, Caris, Chambers, Constable, Crawley, Davis, Evans Kevles, Kline, Knedler, Kusner, Latshaw, Linton, Lufkin, Mitchell, Partridge, Rankin, W. Roberts, Rosengarten, Rothermel, Roulton, Safford, Shohat, Tartler, Weinstein.
PITTSBURGH. Baird, Bohnert, Calkins, Geckeler, Hicks, Hoover, Johnson, Kaltenborn, Mathews, Neelley, Olds, Riggs, Rosenbach, Saibel, Spencer, Swartzel, Taber, Taylor, Whitman.
SALTSBURG. Githens.
SCRANTON. Bertrand.
SELINSGROVE. Williams.
SEWICKLEY. Miller.
STATE COLLEGE. Cohen, Curry, Dunlap, Frink, Gordon, Gravatt, Hamilton, F. W. Owens, H. B. Owens, Rupp, Sheffer, Shibli, Wagner, West.
SWARTHMORE. Dresden, Marriott, Miller.
SWISSVALE. Bobertz, Foraker.
UPPER DARBY. McDonough.
WASHINGTON. Atchison, Bert, Rasel, Shaub, Thomas.
WAYNESBURG. Bond.
WILLIAMSPORT. Smink.

PHILIPPINE ISLANDS. (6)

LAGUNA. Salvosa.
LEYTE. Icamen.
MANILA. Jimenez, Mills, Tan, Tienzo.

PORTO RICO. (3)

MAYAGUEZ. Sanchez-Diaz.
RIO PEDRAS. Horne.
SAN GERMAN. Ramos.

RHODE ISLAND. (22)

NEWPORT. Chase.
EAST PROVIDENCE. Tyler.
PROVIDENCE. Adams, Agnew, Archibald, Astrachan, Bennett, Carlen, Chace, Currier, Gilman, Manning, Morton, Moskovitz, Moyle, Oakley, Richardson, Rosskopf, Smiley, Suesman, Tamarkin, Watt.

SOUTH CAROLINA. (12)

CHARLESTON. Bond, Coleman.
COLUMBIA. Coleman, Jackson, Williams.
GAFFNEY. Thompson.
GREENVILLE. Earle.
GREENWOOD. Weber.
HARTSVILLE. Reaves.
ROCK HILL. Grant, Pugh.
SALUDA. Ramage.

SOUTH DAKOTA. (11)

BROOKINGS. MacDougal, Miller, Rasmusen, Walder.
GLENHAM. Stagner.
HURON. Titt.
MITCHELL. Knox.
RAPID CITY. Bowles, March.
SPEARFISH. Hesseltine.
SPRINGFIELD. Hoopes.

TENNESSEE. (17)

CHATTANOOGA. Perry.
HARROGATE. Messick.
JACKSON. Carr, Walden.
JEFFERSON CITY. White.
KNOXVILLE. Bond, Ghormley.
MARYVILLE. Knapp.
MEMPHIS. Scott.
NASHVILLE. Blair, S. I. Jones, N. P. Miser, W. L. Miser, Peterson, Wren.
PULASKI. Meade.
SPRING HILL. Hume.

TEXAS. (73)

ABILENE. Burnam, Tate.
ALPINE. Gilley.
AMARILLO. Barrick.
AUSTIN. Banks, Barnes, Batchelder, Benedict, Cooper, Craig, Decherd, Dodd, Ettlinger, Feenberg, Horton, Lubben, Mitchell, Moore, Muller, Norbert, Quinn, Vandiver.
BOERNE. Hathaway.
BORGER. May.
BROWNSVILLE. De la Garza.
CANYON. Murray.
COLLEGE STATION. Blumberg, Camp, Finlay, Halperin.
DALLAS. Cell, Dice, E. H. Jones, Reinsch.
DENTON. M. C. Brown, Duncan, Hughes, Oldham.
EL PASO. Kennedy.
FORT WORTH. Howard, Sherer.
GALVESTON. Underwood, Van Fleet.
GEORGETOWN. Wapple.
HOUSTON. Blau, Blumenthal, Bray, Dean, Evans, Ford, Lovett, P. K. Rees, W. A. Rees, Streetman.
LUBBOCK. Edmonson, Sparks, Thompson, Underwood.

MARSHALL. Tinner.
NACOGDOCHES. Cross, Ferguson, Oxsheer.
PRAIRIE VIEW. Randall.
REALITOS. Pickett.
SAN ANTONIO. Hurry, McNelly.
STEPHENVILLE. McSweeny, Redden.
TYLER. Holmes, Nelson.
WACO. Harrell.
WAXAHACHIE. Newton.
WICHITA FALLS. Adams, Shirley.

UTAH. (3)

SALT LAKE CITY. Gibson, Pehrson, Unseld.

VERMONT. (11)

BURLINGTON. Bullard, Butterfield, Donahue, Millington, Swift, Thomas.
MIDDLEBURY. Hazeltine, Perkins, Wiley.
NORTHFIELD. Holmes.
WINOOSKI. Alliot.

VIRGINIA. (58)

ASHLAND. Simpson.
BLACKSBURG. Brodie, Hatcher, O'Shaughnessy, Rasche, Williams.
BLUEFIELD. Wright.
BRISTOL. Mize.
CHARLOTTESVILLE. Pinkerton, Stone, Wells.
EMORY. Miller.
ETTRICK. Stokes.
FARMVILLE. Taliaferro.
GREENWAY. Hollis.
HAMPTON. Perkins.
HOLLINS. Dickinson.
LEXINGTON. Byrne, Paxton, Purdie, L. W. Smith, Witt.
LYNCHBURG. Berry, Larew, Pattillo, Wiggin.
MONTEREY. Colaw.
RICHMOND. Gaines, Harris, M. L. Smith, Wheeler.
SALEM. Carpenter.
STAUNTON. Taylor.
SWEET BRIAR. Moody, Morenus.
UNIVERSITY. Bruce, Buchanan, Echols, Linfield, Luck, Oglesby, Sparrow, Thornton.
VIRGINIA BEACH. Huber, Wunder.
WILLIAMSBURG. Russell, Stetson.

WASHINGTON. (17)

PULLMAN. Butler, Isaacs.
SEATTLE. Ballantine, Carlson, Cramlet, Jerbert, McFarlan, Moritz, Mullemeister, Neikirk, Winger.
SPOKANE. Buxton.
TACOMA. Hanawalt, Martin.
WALLA WALLA. Bratton, Stewart.
YAKIMA. Whitney.

WEST VIRGINIA. (18)

CHARLESTON. Lanham.
HARPERS FERRY. Drew.
HUNTINGTON. Hackney.
INSTITUTE. Lacy.
INWOOD. Mish.
KEYSER. Wilson.
LEWISBURG. Boyd.
MONTGOMERY. W. F. Smith.
MORGANTOWN. Colwell, Davis, Eiesland, Reynolds, Stewart, Turner, Vehse.
PHILIPPI. Morris.
WHEELING. Bagby, Weimer.

WISCONSIN. (40)

BELOIT. Conwell, Huffer.
LA CROSSE. Adkins.
MADISON. Allen, Bennett, Evans, Hart, Hartung, Ingraham, Langer, Lowney, Skinner, E. S. Sokolnikoff, I. S. Sokolnikoff, Stromovsky, Van Vleck, Weaver, Whitford, Wilson.
MILWAUKEE. Battig, Bear, Beckwith, Evans, Knight, Lewandowski, Parkinson, Pettit, Quarles, Roth, Simpson, Vass.
OSHKOSH. Beenken.
PLATTEVILLE. Warner.
RACINE. Mary Joan.
RIPON. Woodmansee.
RIVER FALLS. Eide.
SUPERIOR. C. W. Smith.
WAUKESHA. Hopkins.
WEST DE PERE. De Cleene.
WISCONSIN RAPIDS. McMillan.

WYOMING. (4)

LARAMIE. Barr, Bellamy, Neubauer, Rechard.

FOREIGN MEMBERS. (Other than Canada.)

ARGENTINE. (2)

BUENOS AIRES, Baidaff, Caruthers.

BELGIUM. (1)

ANTWERP. Vanhee.

BURMA. (1)

RANGOON. Campbell.

CHINA. (3)

CANTON. MacDonald.
NANKING. Chang.
PEKING. Konantz.

FRANCE. (3)

PARIS. Borel, Fréchet, Hadamard.

GERMANY. (4)

BERLIN. Cary.
GÖTTINGEN. Boeder, Bond.
MUNICH. Wieleitner.

GREAT BRITAIN. (5)

CAMBRIDGE. Hardy.
DUBLIN. Rowe.
EDINBURGH. Horsburgh.
NOTTINGHAM. Piaggio.
OXFORD. Frecheville.

HOLLAND. (2)

DELFT. Schouten.
ROTTERDAM. Manning.

INDIA. (3)
ALLAHABAD CITY. Mitra.
CALCUTTA. Prasad.
MADURA. Lockwood.

ITALY. (6)
BOLOGNA. Bortolotti, Enriques, Pincherle.
CAGLIARI. Crudeli.
ROME. Laboccetta.
TURIN. Fubini.

JAPAN. (3)
SENDAI. Hayashi.
TOKYO. Mikami.
PYENGYANG, KOREA. Parker.

NEW ZEALAND. (1)
DUNEDIN. Martyn.

POLAND. (1)
WARSAW. Dickstein.

PORTUGAL. (1)
LISBON. da Cunha.

SOUTH AFRICA. (3)
BLOEMFONTEIN. Arndt.
JOHANNESBURG. Dalton.
RONDEBOSCH. Muir.

SOUTH AUSTRALIA. (1)
ADELAIDE. Wilton.

SPAIN. (1)
MADRID. de Toledo.

SWITZERLAND. (3)
FRIBOURG. Bays.
GENEVA. Fehr.
NEUCHATEL. DuPasquier.

SYRIA. (1)
BEIRUT. Jurdak.

TURKEY. (1)
CONSTANTINOPLE. Mourad.
ISTANBUL. Harshbarger.

UKRAINE. (1)
KIEFF. Kryloff.

RECAPITULATION OF MEMBERSHIP

Individual members November 7, 1931	2,014	
Institutional members November 7, 1931	132	
Total membership November 7, 1931		2,146
Total membership November 20, 1929		2,097

CHARTER MEMBERSHIP

Individual charter members	1,045	
Institutional charter members	52	
Total charter membership		1,097
Net gain in individual members	969	
Net gain in institutional members	80	
Total net gain over charter membership		1,049
Total net gain since November 20, 1929		49

BY-LAWS OF THE MATHEMATICAL ASSOCIATION OF AMERICA (INCORPORATED).

ARTICLE I—NAME, PURPOSE AND CORPORATE SEAL.

1. This organization shall be known as

THE MATHEMATICAL ASSOCIATION OF AMERICA (INCORPORATED).

2. Its object shall be to assist in promoting the interests of mathematics in America, especially in the collegiate field, by holding meetings in any part of the United States or Canada for the presentation and discussion of mathematical papers, by the publication of mathematical papers, journals, books, monographs and reports, by conducting investigations for the purpose of improving the teaching of mathematics, by accumulating a mathematical library and by coöperating with other organizations whenever this may be desirable for attaining these or similar objects.

3. The Corporate Seal of the Association shall have inscribed thereon the name of the Association and the words "Corporate Seal—Illinois."

ARTICLE II—MEMBERSHIP.

1. Any person who is interested in the field of collegiate mathematics shall be eligible for election to membership in the Association.

2. Any institution in which the Calculus is regularly taught shall be eligible for election to institutional membership in the Association. Such an institution shall have the privilege of sending a voting delegate to the meetings of the Association.

3. Election to membership shall be by vote of the Board upon written application from the individual or institution seeking admission, endorsed in the case of individuals by two members of the Association.

4. Those who were admitted to membership in The Mathematical Association of America (unincorporated) prior to October 1, 1920, and were in good standing as such on that date, were thereby admitted to membership in this Association (Incorporated).

ARTICLE III—BOARD OF TRUSTEES AND OFFICERS.

1. The Officers of the Association shall be a President, two (2) Vice-Presidents, a Secretary-Treasurer, a Librarian and three (3) members of a Committee on Official Journal.

2. The control and management of the affairs and funds of the Association shall be vested in a Board of twenty (20) Trustees (hereinafter called the "Board"), who shall be members of the Association. This Board shall consist of the officers of the Association and twelve (12) additional members.

3. The President shall be elected by the Association's members biennially for a term of two years and shall be ineligible for reëlection. The Vice-Presidents shall be elected by the Association's members annually for a term of one year, and four members of the Board shall be elected by the Association's members annually for a term of three years. They shall be eligible for reëlection, but not for more than two (2) consecutive terms. The Secretary-Treasurer, the Librarian, and the Committee on Official Journal, consisting of the Editor-in-Chief, the Manager and one other member, shall be appointed by the Board. All Officers and other Trustees shall hold over until their respective successors are elected or appointed and qualify.

4. The Board shall transact the official business of the Association and shall report its actions at the annual business meeting of the Association and in the official journal. A statement regarding any proposed action of the Board which makes or alters a question of policy shall be published in the official journal, or notice of such proposed action shall be mailed to each member, before final action has been taken, so that members of the Association may make known to the Board their individual views.

5. The Board shall have authority fo fill vacancies *ad interim* in any office, including vacancies in the Board and in the Committee on Official Journal, and to make any other appointments necessary for the transaction of the business of the Association.

6. At all meetings of the Board of Trustees a quorum shall consist of not less than five (5) members and no business may be validly transacted at a meeting at which less than a quorum is present; *provided* that any meeting of the Board, whether or not a quorum be present, may be adjourned to a specified time and place by a majority of the members present without notice to the members at large other than announcement of such meeting. Informal action based on a mail ballot by the members of the Board, if ratified at a properly convened meeting of the Board, shall be as valid and effective as if originally authorized at such meeting.

7. Approximately two months before the date of the annual meeting all members shall be given an opportunity to nominate by mail a candidate for each office to be filled by the members for the ensuing year. Approximately one month before the annual meeting the Board shall announce two candidates for each office to be filled by the members, one being the person who received the highest vote in the nominations and the other being selected from among the several nominees next in order. The election shall be by mail or in person and shall close on the day of the annual meeting.

8. The President shall be the Executive Officer of the Association, shall preside at all meetings of the Board of Trustees and at the annual meeting of the Association. He shall have the usual duties pertaining to his office and such other duties as may from time to time be assigned him by the Board of Trustees.

9. The Vice-Presidents shall, in the absence of the President, have and exercise the powers of the President, their order being determined alphabetically. The Board of Trustees may assign to the Vice-President such duties as may from time to time be determined.

10. The Secretary-Treasurer shall have the usual duties pertaining to the Office of Secretary and of Treasurer, including the custody of the records of the Association and of its Corporate Seal, the keeping of minutes of the meetings of the Board of Trustees and of the annual meeting and special meetings of members, and giving of due notice of all regular and special meetings of the Association and of the Board of Trustees and the supervision and safekeeping of the funds of the Association. The Secretary-Treasurer shall also have the duty of seeing that whenever Trustees are elected, including the election of Trustees to fill vacancies, a Certificate, under the Seal of the Association, giving the names of those elected and the term of their office, shall be recorded in the Office of the Recorder of Deeds for Cook County, Illinois. Such Certificates shall be signed by the Secretary-Treasurer and verified by oath of the President.

11. The Committee on Official Journal shall have supervision of the official journal subject to the control of the Board of Trustees.

12. The Librarian shall have general charge of the library of the Association and shall direct its affairs, including the exchange of the publications of the Association, subject to the control of the Board.

Article IV—Meetings.

1. A meeting of the Association shall be held annually, at such time and place as the Board may direct. Special meetings of the Association may be called from time to time by the Board, or while the Board is not in session by the President of the Association, to be held at such time and place as may appear from the call.

2. The outgoing Board shall hold a meeting immediately preceding the annual meeting of the Association next succeeding their election, and the members of the new Board shall hold a meeting and organize, by completing the Board, immediately succeeding the annual meeting of the Association at which the new members thereof were elected. Further meetings of the Board may be held from time to time at the call of the President or of any three (3) members of the Board.

3. Notice of any meeting of members of the Association shall be given by the Secretary-Treasurer at least thirty (30) days prior to the date set for each meeting. Notice of all meetings of the Board other than the regular meetings, provided in Section 2 shall be given to each member of the Board at least fifteen (15) days prior to the date set therefor.

4. Any member of the Association or of the Board may waive notice with the same effect as if due notice had been given him.

5. At all meetings of the Association a quorum shall consist of not less than twenty-five (25) members and no business may be validly transacted at a meeting at which less than a quorum is present; *provided* that any meeting of the Association, whether or not a quorum be present, may be adjourned to a specified time and place by a majority of the members present without notice to the members at large other than the announcement at such meeting.

6. Members may take part and vote in person or by proxy at all meetings of the Association.

Article V—Sections.

1. Any group of not less than ten (10) members of this Association may petition the Board for authority to organize a Section of the Association for the purpose of holding local meetings. The Board shall have power to specify the conditions under which such authority shall be granted.

2. The Association shall not be obligated to pay from its treasury any of the expenses of such Sections.

ARTICLE VI—OFFICIAL PUBLICATIONS.

1. The Association shall publish an official journal, which shall be sent free to all members of the Association in accordance with Article VII.

2. The Board shall have full control of the publication and sale of the official journal and of all other official publications.

3. The official journal shall be under the general management of the Committee on Official Journal. There shall also be appointed by the Board a body of Associate Editors who shall give assistance in connection with the official journal and under the direction of the Committee on Official Journal.

4. The Board shall from time to time, as the need arises, make special provision for the management of any other official publications.

5. The Board shall fix the price of the official journal and of any other official publications of the Association, but in no case shall the journal be sold to non-members for less than the annual dues of individual members.

ARTICLE VII—DUES.

1. Individual members of the Association shall pay an initiation fee of Two Dollars ($2) at the time of election.

2. The annual dues of each individual member shall be four Dollars ($4), including a subscription to the official journal.

3. The annual dues of each institutional member shall be Seven Dollars ($7), including two (2) subscriptions to the official journal.

4. All dues shall be payable on the first of January of each year. Should the annual dues of any member remain unpaid beyond a reasonable time, his name shall be dropped from the list after due notice.

5. New members entering the Association after April 1 of any year shall have their dues pro-rated for the balance of the year, except when they desire to receive the full current volume of the official journal.

6. The life membership fee shall be the present value, according to McClintock's Male Annuitant Table based upon four (4) per cent interest, of an annuity due of Four Dollars ($4) a year at the attained age of the member; an annual valuation of the life membership fund shall be made under the McClintock Male Four (4) Per Cent Table; and the reserve thus computed shall be held as a liability.

ARTICLE VIII—AMENDMENTS TO THE ARTICLES OF ASSOCIATION AND BY-LAWS

1. Changes in the Articles of Association or amendments to the By-Laws may be made at any annual meeting of the Association, or at any adjourned session thereof, or at any special meeting of the Association called for such purpose, by a two-thirds ($\frac{2}{3}$) vote of those present and entitled to vote; *provided* that due notice concerning such amendment shall have been printed in the official journal, or mailed to each member, at least one (1) month before the date of such meeting.

2. No changes in the Articles of Association shall have legal effect until a certificate thereof, verified by oath of the President and under Seal of the Association, attested by the Secretary-Treasurer, shall be filed in the office of the Secretary of State of the State of Illinois and recorded in the office of the Recorder of Deeds for Cook County, Illinois.

PERIODS OF SERVICE OF THE OFFICERS OF THE ASSOCIATION

PRESIDENTS

E. R. HEDRICK 1916
FLORIAN CAJORI 1917
E. V. HUNTINGTON 1918
H. E. SLAUGHT 1919
D. E. SMITH 1920
G. A. MILLER 1921
R. C. ARCHIBALD 1922
R. D. CARMICHAEL 1923
H. L. RIETZ 1924
J. L. COOLIDGE 1925
DUNHAM JACKSON 1926
W. B. FORD 1927–1928
J. W. YOUNG 1929–1930
E. T. BELL 1931–

VICE-PRESIDENTS

E. V. HUNTINGTON 1916
G. A. MILLER 1916
D. N. LEHMER 1917, 1918
OSWALD VEBLEN 1917
J. W. YOUNG 1918, 1926
R. G. D. RICHARDSON 1919
H. L. RIETZ 1919
HELEN A. MERRILL 1920
E. J. WILCZYNSKI 1920
R. C. ARCHIBALD 1921
R. D. CARMICHAEL 1921, 1922
B. F. FINKEL 1922
A. B. CHACE 1923
L. P. EISENHART 1923
J. L. COOLIDGE 1924
DUNHAM JACKSON 1924, 1925
A. A. BENNETT 1925
W. B. FORD 1926
A. J. KEMPNER 1927, 1928
CLARA E. SMITH 1927
F. D. MURNAGHAN 1928
E. T. BELL 1929, 1930
W. C. GRAUSTEIN 1929, 1930
ARNOLD DRESDEN 1931
C. N. MOORE 1931

SECRETARY-TREASURER.

(Appointed by the Trustees after 1918)

W. D. CAIRNS 1916–

COMMITTEE ON OFFICIAL JOURNAL.

(Appointed by the Trustees.)

H. E. SLAUGHT 1916–
R. D. CARMICHAEL 1916–1918
W. H. BUSSEY 1916–1918
R. C. ARCHIBALD 1919–1921
W. A. HURWITZ 1919–1921
A. A. BENNETT 1922
H. P. MANNING 1921–1922
W. B. FORD 1923–1925
J. L. COOLIDGE 1923
A. J. KEMPNER 1924–
W. H. BUSSEY 1926–1931
W. B. CARVER 1932–

ELECTED MEMBERS OF THE BOARD

D. N. LEHMER 1916–1918, 1922–1924, 1930–
R. E. MORITZ 1916–1918
K. D. SWARTZEL 1916
OSWALD VEBLEN 1916, 1920–1922, 1926–1931
R. C. ARCHIBALD 1916–1917, 1923–1930
FLORIAN CAJORI 1916, 1918–1923, 1926–1930
M. B. PORTER 1916–1917
J. W. YOUNG 1916–1917, 1920–1922
B. F. FINKEL 1916–1921, 1930–
E. H. MOORE 1916–1921, 1923–1928
ALEXANDER ZIWET 1916–1918
E. R. HEDRICK 1917–1922, 1924–1929
J. N. VAN DER VRIES 1916–1918
HELEN A. MERRILL 1917–1919
D. E. SMITH 1917–1919, 1921–1926
ELIZABETH B. COWLEY 1918–1920
G. A. MILLER 1918–1920, 1922–1924
E. J. WILCZYNSKI 1918–1919, 1922–1926
L. P. EISENHART 1919–1922, 1925–1930
E. V. HUNTINGTON 1917, 1919–1927
E. L. DODD 1920
R. D. CARMICHAEL 1920, 1924–1929
A. A. BENNETT 1921, 1930–
H. L. RIETZ 1921–1923, 1925–1930
C. F. GUMMER 1921–1925
DUNHAM JACKSON 1923–1929
CLARA E. SMITH 1923–1925
A. B. CHACE 1924–1925
J. L. COOLIDGE 1926–1931
E. T. BELL 1927–1928
E. P. LANE 1928–
W. B. FORD 1929–
E. R. SMITH 1929
W. L. HART 1930–
LAO G. SIMONS 1930–
L. L. DINES 1931–
T. C. FRY 1931–
J. W. GLOVER 1931–

THE ANNUAL MEETING OF THE MINNESOTA SECTION

The annual meeting of the Minnesota Section of the Mathematical Association of America was held at St. John's University, Collegeville, Minnesota on Saturday, May 16, 1931. Sessions were held at 11:00 o'clock and at 2:30 o'clock with luncheon in the dining room of St. John's University. Professor C. H. Gingrich, chairman of the Section, presided at both sessions.

Eighty-five persons attended the meeting including the following twenty members of the Association: Sister Alice Irene, R. W. Brink, W. H. Bussey, Elizabeth Carlson, H. H. Dalaker, Margaret C. Eide, C. H. Gingrich, W. L. Hart, H. E. Hartig, Dunham Jackson, C. M. Jensen, W. H. Kirchner, L. W. Moench, L. J. Schnell, F. J. Taylor, Ella Thorp, A. L. Underhill, Marion B. White, G. L. Winkelmann, Fredrick Wood.

At the afternoon session a vote of thanks was adopted as a sign of appreciation of the cordial hospitality of St. John's University and the efforts of its department of mathematics. Officers for the following year were elected as follows: Chairman, Margaret C. Eide, State Teachers College, River Falls, Wisconsin; Secretary, A. L. Underhill, University of Minnesota; Members of the Executive Committee, Marion B. White, Carleton College, Northfield; F. J. Taylor, College of St. Thomas, St. Paul; C. M. Jensen, Macalester College, St. Paul.

The following seven papers were presented:

1. "The solution of the differential equation curl curl $A = 0$ in spherical and cylindrical coordinates" by Professor Fredrick Wood, Hamline University.

2. "Properties of a wave equation" by Mr. Edwin N. Oberg, University of Minnesota, by invitation.

3. "Report of the committee on college entrance requirements in geometry" by Professor Dunham Jackson, University of Minnesota.

4. "Mathematics and liberal education" by Professor W. H. Bussey, University of Minnesota.

5. "Correlation between the sex of human siblings in twin and triple births" by Miss Borghild Gunstad, University of Minnesota, by invitation.

6. "The nth derivative of a function of a function" by Mr. Max G. Scherberg, University of Minnesota, by invitation.

7. "Placement tests and high school training in mathematics" by Professor Robert F. Schuck, University of Minnesota, by invitation.

Abstracts of some of these papers follow:

1. In considering the vector potential A for a given field the equation curl $A = 0$ arises. Its relation to $\nabla^2 A = 0$ suggests that a solution may be found by following the usual procedure in solving $\nabla^2 A = 0$. The work is carried out in spherical and cylindrical coordinates and the results are found to be closely related to the solutions of $\nabla^2 A = 0$. That the work can be carried out in other systems of coordinates seems quite possible.